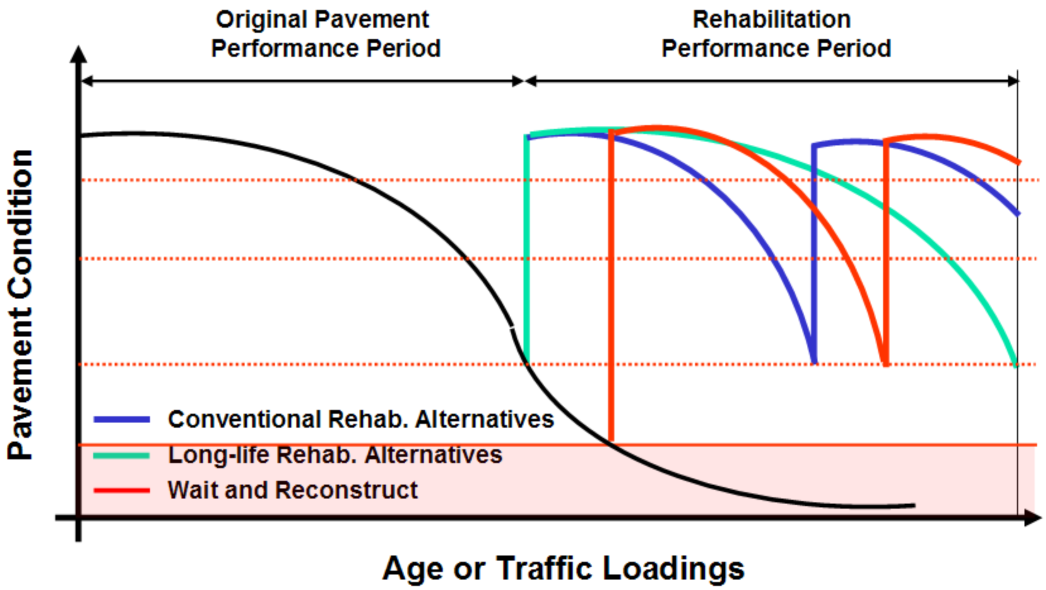
INTERIM
LIFE-CYCLE COST ANALYSIS PROCEDURES MANUAL



Note to the User:

To use this manual, the reader must have Life-Cycle Cost Analysis software program *RealCost, Version 2.2.1*. The program can be downloaded from the FHWA, Office of Asset Management Web site at *http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.htm*

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State of California
Department of Transportation
Pavement Standard Team & Division of Design

CONTENTS

1.0 Purpose of this Manual 1

2.0 Background 1

3.0 LCCA Methodology 2

3.1 Establishing Alternatives 3

3.2 Determining an Analysis Period 4

3.3 Determining Discount Rate 8

3.4 Determining Maintenance and Rehabilitation Frequencies 8

3.5 Estimating Costs 10

3.5.1 Initial Costs 11

3.5.2 Maintenance Costs 12

3.5.3 Rehabilitation Costs 13

3.5.4 Salvage Value 16

3.5.5 User Costs 16

3.6 Calculating Life-Cycle Costs 17

3.7 Analyzing Alternatives 17

4.0 Using *RealCost* 18

4.1 Project-Level Inputs 19

4.1.1 Project Details 20

4.1.2 Analysis Options 21

4.1.3 Traffic Data 24

4.1.4 Value of User Time 28

4.1.5 Traffic Hourly Distribution 29

4.1.6 Added Time and Vehicle Stopping Costs 31

4.1.7 Saving and Loading Project-Level Inputs 33

4.2 Alternative-Level Inputs 33

4.3 Input Warnings 39

4.4 Simulation and Outputs 40

4.5 Administrative Functions 42

5.0 Examples of LCCA 43

5.1 Example One 43

5.1.1 Alternative 1: Full-Depth AC Replacement 43

5.1.2 Alternative 2: Full-depth PCC Replacement 43

5.1.3 Results of the Example 44

5.2 Example Two 47

5.2.1 Alternative 1: Mill and Replace AC (5-year CAPM) 48

5.2.2. Alternative 2 48

5.2.3 Results of the Example 49

REFERENCES 53

APPENDIX 1: List of Limitations to and Bugs in *RealCost* 54

APPENDIX 2: Typical Pavement M&R Schedules for California 56

APPENDIX 3: Maximum Queue Length Estimation 72

APPENDIX 4. State highway traffic hourly Distributions 76

LIST OF FIGURES

Figure 1. Pavement Condition vs. Pavement Life. 7

Figure 2. Pavement M&R Schedule Determination Flow Chart. 10

Figure 3. *RealCost* Input Worksheet. 20

Figure 4. Project Details form. 21

Figure 5. Analysis Options form. 22

Figure 6. Traffic Data form. 25

Figure 7. Value of User Time form. 29

Figure 8.Traffic Hourly Distribution form. 30

Figure 9. Added Time and Vehicle Stopping Costs form. 32

Figure 10. Alternative 1 form (which is identical to the Alternative 2 form). 34

Figure 11. Input Warnings. 40

Figure 12. Deterministic Results form. 41

Figure 13. *RealCost* Report. 42

Figure 14. Typical cross section of project alternatives (Example One). 44

Figure 15. Cost vs. Time diagrams of project alternatives (Example One). 45

Figure 16. *RealCost* Report (Example One). 46

Figure 17. *RealCost* Deterministic Results (Example One). 47

Figure 18. Existing typical cross section (Example Two). 49

Figure 19. Cost vs. Time Diagrams of project alternatives (Example Two). 49

Figure 20. *RealCost* report (Example Two). 50

Figure 21. *RealCost* Deterministic Results 1 (Example Two). 51

Figure 22. *RealCost* Deterministic Results 2 (Example Two). 52

Figure 23. Map of Caltrans Climate Regions. 57

Figure 24. Traffic Demand-Capacity Model ....**Error! Bookmark not defined.**

LIST OF TABLES

Table 1. LCCA Analysis Periods ... 6

Table 2. Sample Pavement M&R Schedules ... 9

Table 3. Agency Project Support Cost Multipliers ... 12

Table 4. Caltrans M&R Construction Unit Costs for Flexible/Rigid Pavements (FY 1999-2004) ... 14

Table 5. Caltrans M&R Construction Unit Costs for Rigid Pavements Only (FY 1999-2004) 15

Table 6. Example of State Highway Annual Traffic Growth ... 25

Table 7. Traffic Input Values ... 27

Table 8. Average State Highway Traffic Hourly Distribution ... 31

Table 9. Consumer Price Indexes for All Urban Consumers ... 33

Table 10. Productivity Estimates of Typical Rehabilitation Strategies for Flexible/Rigid Pavements ... 37

Table 11. Productivity Estimates of Typical Rehabilitation Strategies for Rigid Pavements Only 38

Table 12. Caltrans Climate Region Classification ... 58

Table 13. Maximum Queue Length Estimation ... 74

1.0 PURPOSE OF THIS MANUAL

This manual describes a life-cycle cost analysis (LCCA) procedure to be used by the employees of the California Department of Transportation (Caltrans) and other personnel working on projects on the State Highway System or other roads/facilities funded by Caltrans. The manual provides step-by-step instructions for using *RealCost,* a computer software program developed by the Federal Highway Administration (FHWA) that has been chosen by Caltrans as the official software for evaluating cost-effectiveness of new roadway project alternatives and roadway maintenance and rehabilitation (M&R) project alternatives. The instructions describe in detail how to perform an LCCA in order to assure that the project alternatives are analyzed objectively and consistently statewide regardless of who designs, builds, or funds the project. This manual supplements the FHWA's *RealCost User Manual* (2004). The additional tables, figures, and other resources included in this manual are specifically developed for Caltrans projects and are to guide the data inputs needed for running *RealCost.*

It is Caltrans' policy that life-cycle cost impacts be fully taken into account when making project-level decisions. Further discussion on when and how to apply the LCCA can be found in the Highway Design Manual (HDM), Topic 619. This manual is a "living document," as it will be continuously updated as new data and information arrive.

2.0 BACKGROUND

The LCCA is an analytical technique that is built on well-founded economic principles to evaluate long-term alternative investment options. The analysis enables the total cost comparison of competing design alternatives, each of which is appropriate for implementation of a transportation project. By considering all of the relevant costs (agency and user costs) that occur throughout the life of an alternative, this analytical process helps to identify the lowest cost option to accomplish the project (which ultimately might not be selected after such considerations as available budgets, risk, and political and environmental concerns are taken into account) and provides other critical information for the overall decision-making process.

The FHWA encourages the use of LCCA in analyzing all major investment decisions where such analyses are likely to increase the efficiency and effectiveness of those decisions.

HDM Topics 612 and 619 identify situations where an LCCA must be performed to assist in determining the most appropriate alternative for a project by comparing the life-cycle costs of:

- Different pavement types (flexible, rigid, composite);
- Different rehabilitation strategies;
- Different pavement design lives (e.g., five years versus ten years, ten years versus twenty years, twenty years versus forty years, etc.); and
- Different implementation strategies (combining widening and rehabilitation projects versus building them separately)

3.0 LCCA METHODOLOGY

Once a decision has been made to undertake a project, an LCCA should be conducted as early as possible in the project development process. The level of analysis detail should be consistent with the level of investment.

There are two different approaches in life-cycle cost computation: deterministic and probabilistic. The deterministic approach is a traditional one where the user assigns each LCCA input variable a fixed, discrete value, usually a value most likely to occur that is based on historical data and user judgment. The probabilistic approach is a relatively new one that accounts for the uncertainty and variation associated with input values. By defining uncertain input variables with the frequency (probability) distributions of possible values, this approach allows for the simultaneous computation of differing assumptions for many variables. Probability functions for individual LCCA input variables are still under development at Caltrans, and they are not yet available for use; *therefore this manual only addresses the deterministic approach*.

Following are the steps for performing an LCCA:

1. Establish alternatives;
2. Determine analysis periods;
3. Determine discount rate;
4. Determine maintenance and rehabilitation frequencies;
5. Estimate costs;
6. Calculate life-cycle costs; and
7. Analyze alternatives.

The LCCA procedure described herein was derived from the FHWA's *RealCost User Manual* (2004) and the FHWA's *LCCA Technical Bulletin* (1998), "Life-Cycle Cost Analysis in Pavement Design," both of which can be downloaded from the FHWA Web site at *http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.htm.*

3.1 Establishing Alternatives

An LCCA begins with the development of project design or implementation alternatives that will accomplish the structural and performance objectives for a project. For example, comparisons can be made of asphalt concrete (AC) pavement versus jointed plain concrete pavement; rubberized AC pavement versus conventional dense-graded AC pavement; mill-and-replace AC versus AC overlay (ACOL); and ten-year design life rehabilitation versus twenty-year design life rehabilitation. Each competing alternative must be a properly designed, viable pavement structure that would be approved for construction if selected. HDM Topic 619 lists the minimum requirements for when and what to analyze using an LCCA. See HDM Topic 612 for cases requiring a mandatory or advisory design exception.

The LCCA should not be used for comparing project alternatives that would not yield the same level of service and benefits to the users of the facility (e.g., road rehabilitation versus road capacity expansion) or for comparing projects that would accomplish different objectives (e.g., road realignment versus widening). To perform that sort of analysis, a Benefit-Cost Analysis (BCA), which considers the benefits of an alternative as well as its costs, should be used. For details on BCA, refer to the Cal-B/C (California Life-Cycle Benefit/Cost Model) user manuals and technical supplements, which are available from the Division of Transportation Planning at *http://www.dot.ca.gov/hq/tpp/planning_tools/tools.htm.*

3.2 Determining an Analysis Period

The *analysis period* is the timeframe during which the initial and future costs for the alternatives will be evaluated. The LCCA assumes that the pavement will be properly maintained and rehabilitated to carry the projected traffic over the specified analysis period.

Table 1 provides analysis periods for comparing alternatives with different pavement design lives. For example, twenty-year and thirty-five year analysis periods should be used if five-year and twenty-year design life project alternatives are compared; a thirty-five year analysis period should be used if both alternatives are designed for a twenty-year design life; and thirty-five-year and fifty-five-year analysis periods should be used for comparing twenty-year and forty-year design life project alternatives.

Table 1. LCCA Analysis Periods

	Alternative 2 Design Life			
Alternative 1 Design Life	5-Yr	10-Yr	20-Yr	40-Yr
5-Yr	1) 20 yrs (PV) 2) 20 yrs (PV)	1) 20 yrs (PV) 2) 20 yrs (PV)	1) 20 yrs (EUAC) 2) 35 yrs (EUAC)	1) 20 yrs (EUAC) 2) 55 yrs (EUAC)
10-Yr	1) 20 yrs (PV) 2) 20 yrs (PV)	1) 20 yrs (PV) 2) 20 yrs (PV)	1) 35 yrs (PV) 2) 35 yrs (PV)	1) 35 yrs (EUAC) 2) 55 yrs (EUAC)
20-Yr	1) 35 yrs (EUAC) 2) 20 yrs (EUAC)	1) 35 yrs (PV) 2) 35 yrs (PV)	1) 35 yrs (PV) 2) 35 yrs (PV)	1) 35 yrs (EUAC) 2) 55 yrs (EUAC)
40-Yr	1) 55 yrs (EUAC) 2) 20 yrs (EUAC)	1) 55 yrs (EUAC) 2) 35 yrs (EUAC)	1) 55 yrs (EUAC) 2) 35 yrs (EUAC)	1) 55 yrs (PV) 2) 55 yrs (PV)

* PV: Present Value; EUAC: Equivalent Uniform Annual Cost

PV (present value) is the total value of present and future expenses converted to today's dollar amounts, and it is calculated using the following equation:

$$PV = F\frac{1}{(1+i)^n}$$

where F = future dollar at the end of nth years
i = discount rate
n = number of years

EUAC is the equivalent uniform annual cost, and it represents the yearly costs of an alternative as if they occurred uniformly throughout the analysis period. EUAC can be calculated as follows:

$$EUAC = PV\frac{i(1+i)^n}{(1+i)^n - 1}$$

When comparing two project alternatives with different analysis periods [for example, a five-year design life alternative (twenty-year analysis period) versus a twenty-year design life alternative (thirty-five-year analysis period)], it will be necessary to run *RealCost* twice, once for each alternative with its analysis period. After that, it is possible to compare the EUAC of each project alternative (see Table 1).

Reasonable, feasible initial construction, maintenance, and rehabilitation strategies must be established for the analysis period. When a pavement is first constructed or rehabilitated, it is in good condition but as it ages its condition gradually deteriorates to a point where some type of maintenance or rehabilitation treatment is warranted. Figure 1 shows the cycle of construction, pavement condition, and maintenance/rehabilitation that a pavement undergoes.

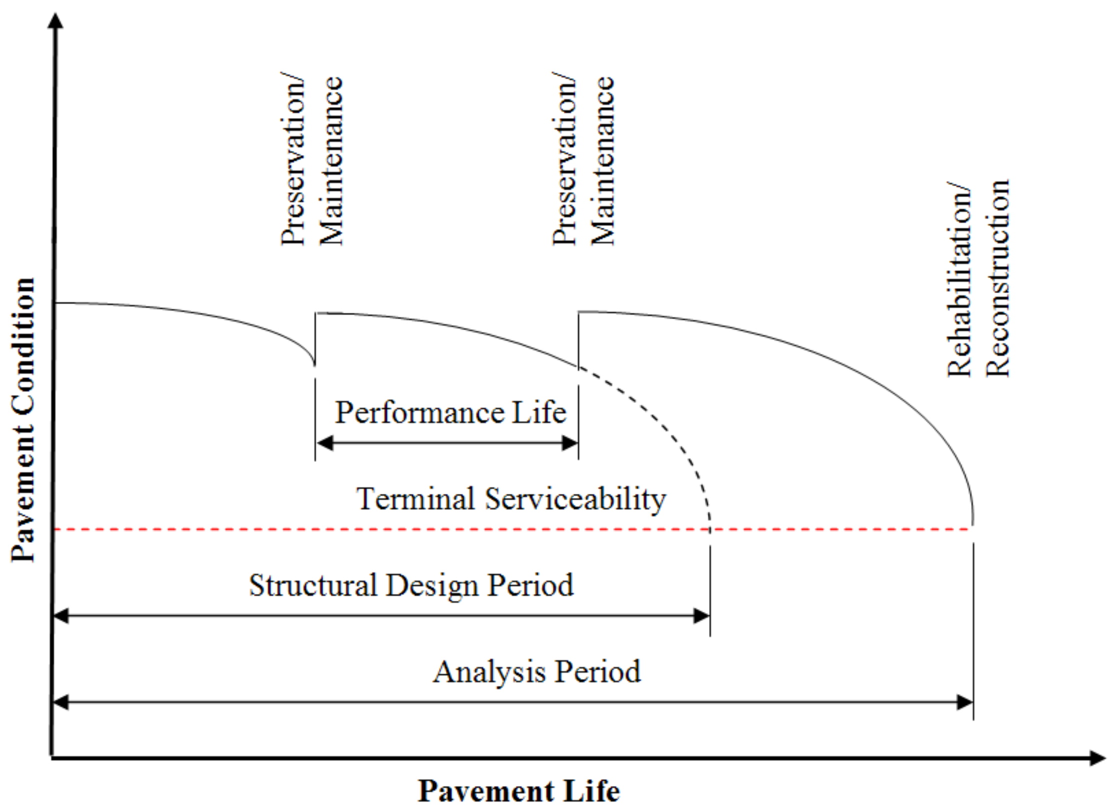


Figure 1. Pavement Condition vs. Pavement Life.

Information on performance and M&R strategies for various pavements are discussed further in Section 3.4, "Determining Maintenance and Rehabilitation Frequencies."

3.3 Determining Discount Rate

Discount rate is the interest rate by which future expenditures (in constant or base year dollars) will be converted to present value. It is commonly known as a "real discount rate" as it reflects only the opportunity value of time, without including the general rate of inflation. Real discount rates typically range from 3 percent to 5 percent, representing the prevailing interest rate on borrowed funds less inflation. *Caltrans currently uses a discount rate of 4 percent in the LCCA of pavement structures.*

3.4 Determining Maintenance and Rehabilitation Frequencies

After the viable project alternatives are identified, a pavement M&R schedule for each one must be developed. A pavement M&R schedule typically includes preventive and corrective maintenance through the HM-1 Major Maintenance program and pavement rehabilitation through Capital Preventive Maintenance (CAPM) and roadway rehabilitation programs. Pavement M&R schedules vary depending on the project site's climate region, the existing pavement and final surface types, the assigned maintenance service level (MSL, the state highway classification used by the Division of Maintenance for maintenance programming purposes), and the initial M&R strategy.

Table 2 shows pavement M&R schedule examples for flexible pavements with OGAC (open graded AC overlay) in the coastal region. A complete set of pavement M&R schedules can be found in Appendix 2, where they have been grouped by four climate regions (Coastal, Valley, Desert, and Mountain) based on annual average temperature and precipitation level. These pavement M&R schedules are derived from the "Pavement M&R Decision Trees" prepared by each Caltrans district.

Table 2. Sample Pavement M&R Schedules

Climate Region	Maint. Service Level	Existing Pavement/Final Surface Type	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Coastal	1, 2, 3	Flexible w/ OGAC	20yr New Pavement, Rehab 10yr	Year of Action	19	34	49	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			20yr New Pavement, Rehab 20yr	Year of Action	20	40		
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)		TBD (Replace OGAC every 4-6 years)
			40yr New Pavement, Rehab 20yr	Year of Action	41			
				Strategy	ACOL w/ OGAC (Rehab 20yr)			TBD (Replace OGAC every 4-6 years)
			CAPM 5yr	Year of Action	0	10	20	
				Strategy	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	TBD (Replace OGAC every 4-6 years)
			CAPM 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 20yr	Year of Action	0	25	50	
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 40yr	Year of Action	0	40		
				Strategy	ACOL w/ OGAC (Rehab 40yr)	ACOL w/ OGAC (Rehab 40yr)		TBD (Replace OGAC every 4-6 years)

In order to find an applicable pavement M&R schedule (i.e., an initial M&R strategy) for a project alternative in Appendix 2, follow the logical sequence in Figure 2, then select the one that matches the project site's climate region and the existing pavement's maintenance service level.

Each pavement M&R schedule in Appendix 2 includes timings for future major M&R activities (CAPM or Rehabilitation). Because of space limitations, all the in-between preventive and corrective maintenance treatments (such as, crack seal, chip seal, slurry seal, dig-out, replacement of open graded friction course under the HM-1 program) are not shown in the schedules. However, an equivalent annual cost for those maintenance activities is provided for each pavement M&R schedule.

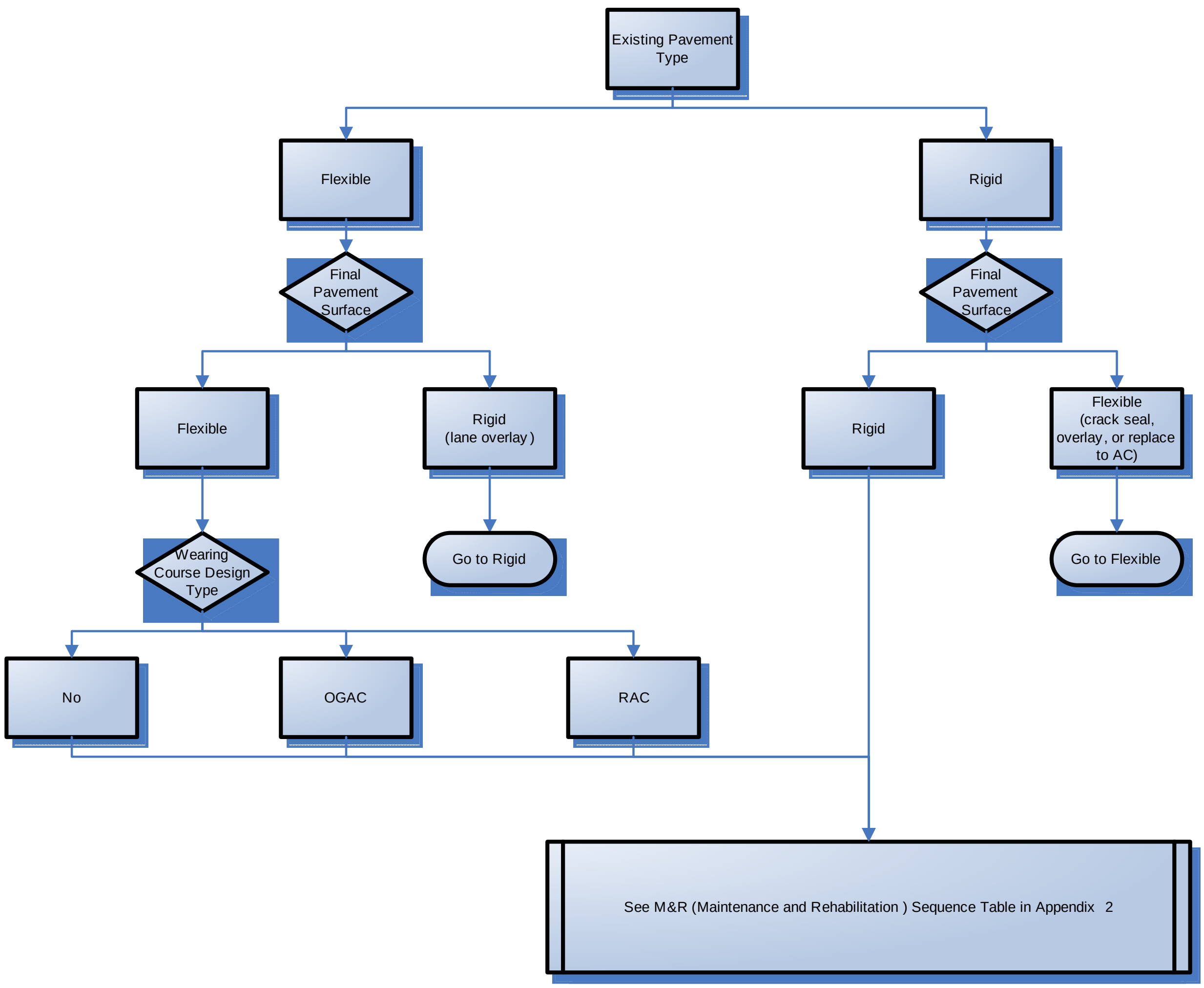


Figure 2. Pavement M&R Schedule Determination Flow Chart.

3.5 Estimating Costs

Although the LCCA addresses all the costs anticipated over the service life of the facility, the analysis does not necessarily require calculation of all the costs associated with each alternative.

Instead, only differential costs between alternatives may to be considered because costs common to each alternative eventually cancel out. The total cost includes initial costs, maintenance costs, rehabilitation costs, user costs, and salvage value.

3.5.1 Initial Costs

Initial costs include estimated construction costs as well as project support costs (for design, environment, construction administration and inspection, project management, etc.) to be borne by an agency for implementing a project alternative. Construction costs for each alternative should be determined from the engineer's estimates if available [see the Project Development Procedures Manual (PDPM) for estimating costs and the summary sheets included in the Project Initiation Document (PID) and the Project Report (PR)] and should include all the costs required for mainline pavement, base, subbase, shoulders, shoulder base, shoulder subbase, drainage, joint seals, earthwork, traffic control, time-related overhead, mobilization, supplemental work, and contingencies. Construction costs common to both alternatives — such as bridges, traffic signage, and striping — may be excluded if those costs can be identified with little effort.

Project support costs, expressed as percentages of construction costs, should be decided based on the proposed work plan for project alternatives. Where work plan data are not available yet, the project support cost multipliers shown in Table 3 may be used to estimate project support costs that will likely be required for a project alternative.

Suppose that one project alternative being considered is a five-year CAPM ACOL with an estimated construction cost of $ 4.0 million. Corresponding project support cost multipliers for this CAPM alternative would be 0.18 with right-of-way and 0.15 without right-of-way, respectively. Accordingly, the respective initial costs for this alternative would be estimated at $4.72 million ($4.0 million for construction and $0.72 million for project supports) with right-of-way and $4.6 million ($4.0 million for construction and $0.6 million for project supports) without right-of-way.

Table 3. Agency Project Support Cost Multipliers

Type of Project		Range of Project ($)	Multiplier w/ Right-of-Way	Multiplier w/o Right-of-Way
New Construction	Small	750,000 - 5,000,000	0.47	0.39
	Medium	5,000,001 - 20,000,000	0.31	0.29
	Large	20,000,001 - 35,000,000	0.25	0.23
	Very Large	35,000,001 - Up	0.24	0.20
Widening	Small	750,000 - 2,500,000	0.56	0.52
	Medium	2,500,001 - 5,000,000	0.39	0.35
	Large	5,000,001 - 15,000,000	0.28	0.26
	Very Large	15,000,001 - Up	0.25	0.24
CAPM	Small	750,000 - 2,000,000	0.19	0.19
	Medium	2,000,001 - 5,000,000	0.18	0.15
	Large	5,000,001 - Up	0.16	0.13
Rehabilitation	Small	750,000 - 2,000,000	0.35	0.31
	Medium	2,000,001 - 5,000,000	0.28	0.26
	Large	5,000,001 - Up	0.20	0.19
Realignment	Small	750,000 - 2,000,000	0.65	0.60
	Medium	2,000,001 - 5,000,000	0.67	0.58
	Large	5,000,001 - Up	0.31	0.29

3.5.2 Maintenance Costs

Maintenance costs include costs for preventive or corrective maintenances, such as joint and crack sealing, void undersealing, chip seal, patching, spall repair, individual slab replacements, thin ACOL, etc., the purpose of which is to extend the service life of previously carried-out major M&R activity. Refer to Appendix 2 for an equivalent annual cost for these maintenance activities for the selected pavement M&R schedule. These costs are based on Caltrans historical data collected by the Division of Maintenance.

3.5.3 Rehabilitation Costs

Rehabilitation costs are associated with future major M&R activities (CAPM or Rehabilitation) scheduled to be performed after implementing a project alternative. Rehabilitation costs for a particular major M&R activity should include costs for project support and costs for all the appurtenant and supplemental works to drainage, safety, and other features, made necessary by the major M&R activity.

Table 4 and Table 5 summarize the average lane-mile construction costs (excluding project support costs) of various CAPM and rehabilitation strategies implemented by Caltrans over the last six years for flexible/rigid pavements and rigid pavements only, respectively. To estimate rehabilitation costs for each major M&R activity included in the selected M&R schedule, take the applicable average lane-mile construction cost (either from Table 4 or Table 5), calculate construction costs by multiplying the average lane-mile cost by total lane-miles to be treated, and add project support costs by applying applicable project cost multipliers to the construction costs.

Table 4. Caltrans M&R Construction Unit Costs for Flexible/Rigid Pavements (FY 1999-2004)

Strategy Type	Strategy Alternative	Route Class	No. of Project	Total Lane-Mile	$/Lane-Mile		
					Minimum	Maximum	Weighted Average
5-Yr CAPM	ACOL FLEX	1	21	753	41,664	191,183	**92,637**
		2	22	507	60,667	169,514	**104,096**
		3	7	293	68,122	149,302	**105,887**
	MILL & REPL AC	1	--	--	--	--	--
		2	7	203	47,622	184,904	**95,411**
		3	--	--	--	--	--
	RAC	1	23	1,392	28,245	220,433	**85,591**
		2	26	550	64,056	176,372	**106,892**
		3	4	131	31,791	157,067	**84,835**
10-Yr CAPM	ACOL FLEX*	1	--	--	--	--	**110,300**
		2	--	--	--	--	**124,000**
		3	--	--	--	--	**126,100**
	MILL & REPL AC*	1	--	--	--	--	--
		2	--	--	--	--	**113,600**
		3	--	--	--	--	--
	RAC*	1	--	--	--	--	**101,900**
		2	--	--	--	--	**127,300**
		3	--	--	--	--	**101,000**
10-Yr REHAB.	ACOL FLEX	1	54	1,386	133,611	737,800	**292,654**
		2	46	634	140,581	1,553,264	**334,941**
		3	--	--	--	--	--
	MILL & REPL AC	1	24	657	35,448	677,176	**258,134**
		2	10	135	146,269	979,310	**406,287**
		3	3	33	222,700	925,556	**302,045**
	RAC	1	12	389	105,802	781,818	**260,099**
		2	15	207	143,073	446,357	**235,198**
		3	--	--	--	--	--
20-Yr REHAB.	ACOL FLEX*	1	--	--	--	--	**324,800**
		2	--	--	--	--	**371,800**
		3	--	--	--	--	--
	MILL & REPL AC*	1	--	--	--	--	**286,500**
		2	--	--	--	--	**451,000**
		3	--	--	--	--	**335,300**
	RAC*	1	--	--	--	--	**288,700**
		2	--	--	--	--	**261,100**
		3	--	--	--	--	--

* Based upon the 2005 Caltrans' study, "Pavement Service Life Cost Analysis," by the Division of Design.

Table 5. Caltrans M&R Construction Unit Costs for Rigid Pavements Only (FY 1999-2004)

Strategy Type	Strategy Alternative	Route Class	No. of Project	Total Lane-Mile	$/Lane-Mile		
					Minimum	Maximum	Weighted Average
5-Yr CAPM	ACOL RIGID	1	2	102	68,203	101,856	**81,042**
		2	--	--	--	--	--
		3	--	--	--	--	--
	CPR	1	1	18	1,300	38,826	**167,083**
		2	2	--	--	--	--
		3	3	--	--	--	--
	GRINDING	1	21	1,725	28,856	191,058	**72,832**
		2	4	137	65,858	125,881	**83,700**
		3	--	--	--	--	--
10-Yr CAPM	ACOL RIGID*	1	--	--	--	--	**96,500**
		2	--	--	--	--	--
		3	--	--	--	--	--
	CPR*	1	--	--	--	--	**97,600**
		2	--	--	--	--	--
		3	--	--	--	--	--
	GRINDING*	1	--	--	--	--	**96,800**
		2	--	--	--	--	**99,700**
		3	--	--	--	--	--
10-Yr REHAB.	ACOL RIGID	1	15	609	91,764	678,341	**231,717**
		2	2	100	218,283	773,626	**370,653**
		3	--	--	--	--	--
	CPR	1	10	349	132,843	952,326	**307,699**
		2	--	--	--	--	--
		3	--	--	--	--	--
	GRINDING	1	--	--	--	--	--
		2	3	139	172,820	1,032,857	**247,874**
		3	--	--	--	--	--
	PCC OVERLAY	1	1	21	979,710	979,710	**979,710**
		2	--	--	--	--	--
		3	--	--	--	--	--
20-Yr REHAB	ACOL RIGID*	1	--	--	--	--	**257,200**
		2	--	--	--	--	**411,400**
		3	--	--	--	--	--
	CPR*	1	--	--	--	--	**341,500**
		2	--	--	--	--	--
		3	--	--	--	--	--
	GRINDING*	1	--	--	--	--	--
		2	--	--	--	--	**275,100**
		3	--	--	--	--	--
	PCC OVERLAY*	1	--	--	--	--	**1,087,500**
		2	--	--	--	--	--
		3	--	--	--	--	--

* Based upon the 2005 Caltrans' study, "Pavement Service Life Cost Analysis," by the Division of Design.
3.5.4

Salvage Value

Salvage value is the estimated remaining value of a project at the end of the analysis period. Generally, if an alternative has reached its full life-cycle at the end of the analysis period, it is considered to have no salvage value. If it has not reached its full life-cycle, it is considered to have a salvage value. Salvage value can be determined as follows:

$$\text{Salvage value} = \text{Cost of last constr/rehab}\ x\ \frac{\text{Expected remaining life of last const/rehab}}{\text{Total expected life of last const/rehab}}$$

For example, if a forty-year analysis is conducted and a $250,000 rehabilitation strategy with a ten-year design life is applied in year 35, the salvage value at year 40 is $125,000. Generally, salvage value tends to be small if it is spread out over a long analysis period.

3.5.5 User Costs

Best-practice LCCA calls for consideration of not only agency costs (for initial construction and future M&R activities), but also costs to facility users. User costs include travel time costs, vehicle operating costs, and crash costs incurred by the traveling public. Such user costs typically arise when work zones are imposed for fieldwork, which restricts the normal capacity of the facility and reduces traffic flow. User costs are also incurred during normal operations but they are often similar between project alternatives and may be removed from most analyses. Additional user costs resulting from work zones can become a significant factor when a large queue occurs in one alternative but not in the other.

3.6 Calculating Life-Cycle Costs

In the previous steps, project alternatives were defined with respect to agency costs, user costs, salvage value, and the timing of initial construction and future M&R activities. This step, *calculation of life-cycle costs*, involves calculation of the total life-cycle costs of each alternative so that they may be directly compared. Since dollars spent at different times have different present values, the anticipated costs for future M&R activities for each alternative need to converted to present dollar values and summed up using the economic technique "discounting." The most cost-effective alternative can then be determined by comparing the life-cycle costs (in form of PV or EUAC) of the different alternatives.

3.7 Analyzing Alternatives

This step, *analyzing alternatives*, involves analyzing and interpreting the LCCA results from the previous step, *calculating life-cycle costs*.

There are many factors from which to choose when beginning the comparison. For example, one of the first things to consider might be the user costs proportion comprising total life-cycle costs for the alternatives. For projects proposed on highway corridors with large traffic volumes, user costs can be significantly greater than agency costs, so it might be necessary to consider assigning a different weighting factor to the user costs. These costs for each alternative, adjusted or not, can then be compared to see if one of them has a disproportionately high or low impact on users.

If the lowest agency cost alternative also has a disproportionately high user cost impact, this information should be used either to revisit the alternative's traffic management aspect or to reconsider an alternative that might have somewhat higher agency costs but much lower user costs. Also, the lowest agency cost alternative may not necessarily be the best solution since there are also other factors that should be addressed, such as safety and air pollution, and non-user and business impacts resulting from reduced or restricted traffic.

If a higher life-cycle cost alternative is selected over a lower cost one, the justification for the decision should be entered into the PID, PR, or other appropriate project document. In these instances, design exceptions may be needed as well (see HDM Topic 612). However, for analysis purposes, alternatives with life-cycle costs that are within 10 percent of each other over the same analysis period are considered to be equivalent, meaning that either one can be considered to have the lower life-cycle cost.

4.0 USING *REALCOST*

In order to prepare a life-cycle cost estimate using *RealCost*, install version 2.2.1 onto your computer. The software can be obtained by downloading it from the FHWA's Office of Asset Management Web site: *http://www.fhwa.dot.gov/infrastructure/asstmgmt/lccasoft.htm.* Follow the installation instructions provided on the Web site. [Because *RealCost* is an add-on program designed to run in Microsoft *Excel* 2000 (or later), it does not require installation by Caltrans' IT staff.] After you install it, select "*RealCost* 2.2" from the *Windows* "Start Menu" (Programs > *RealCost* > *RealCost* 2.2) to launch the program.

When prompted for Macro options, choose "Enable Macros" to run *RealCost*. When it opens, an "Input Spreadsheet" window — which resembles an *Excel* spreadsheet — appears onscreen. Immediately after that window appears, the "Switchboard" panel opens on top of it (see Figure 3). This Switchboard provides two options for inputting values. This manual contains instructions for entering information by using the Switchboard, but if you want to directly input your values into the Input Worksheet, you can close the Switchboard by clicking the “x” in its upper right-hand corner. If you want to restore it later, you can do so by clicking “RealCost” on the menu bar at the top of the window, and selecting “RealCost Switchboard.”

As Figure 3 shows, the Switchboard consists of five sections: Project-Level Inputs; Alternative-Level Inputs; Input Warnings; Simulation and Output; and Administrative Functions. These five items and their functions are discussed in Sections 4.1 through 4.5. *(Note:* most of the functions available from the Switchboard are also accessible from the “RealCost” menu item.)

4.1 Project-Level Inputs

RealCost requires two levels of information. The first, “Project-Level Inputs,” which are discussed in this section, are project-level data that applies to all the project alternatives being considered. The second information level, “Alternative-Level Inputs” (discussed in Section 4.2), are data that define the differences between project alternatives (e.g., agency costs and work zone specifics for each alternative’s component activities). To emphasize the difference between the two types of inputs, *RealCost* requires that they be entered separately.

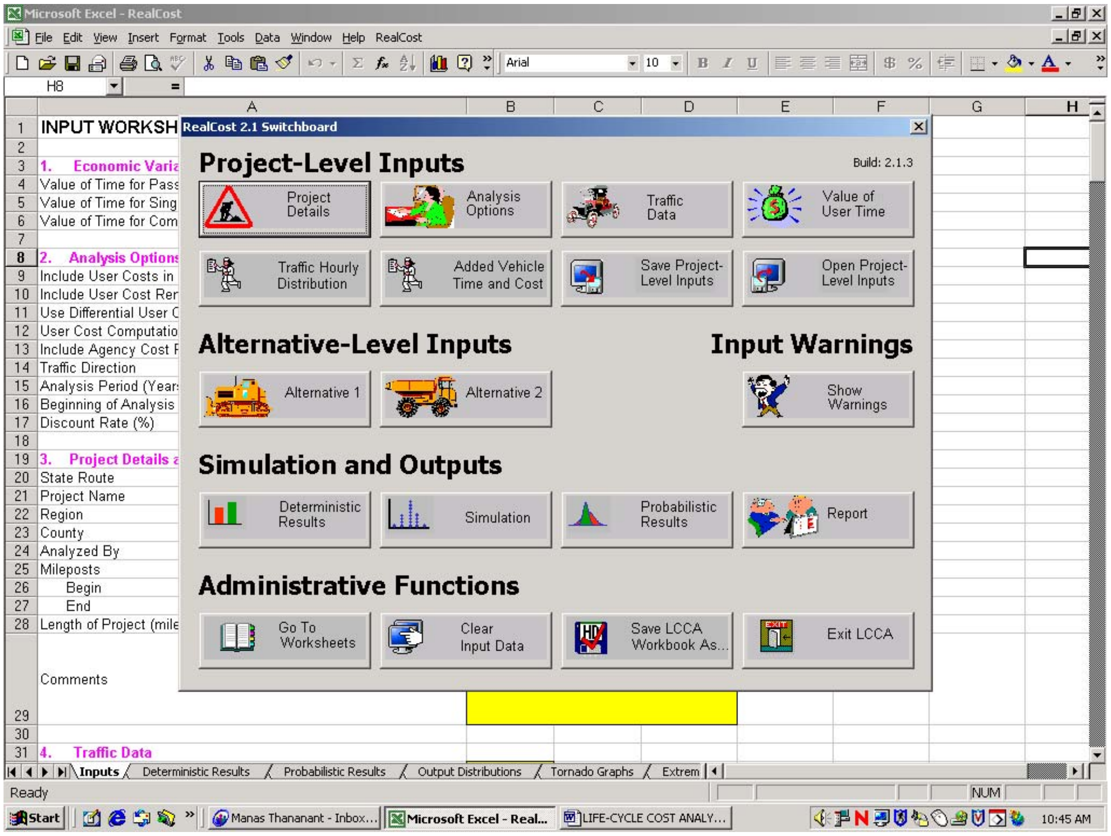


Figure 3. *RealCost* Input Worksheet.

4.1.1 <u>Project Details</u>

The “Project Details” form (Figure 4) is used to enter the project documentation details. Enter the data according to the field names. Note that only the milepost data entered here will be used in the analysis. Once you have entered all the project documentation details, click the “Ok” button to return to the Switchboard or the “Cancel” button to start over.

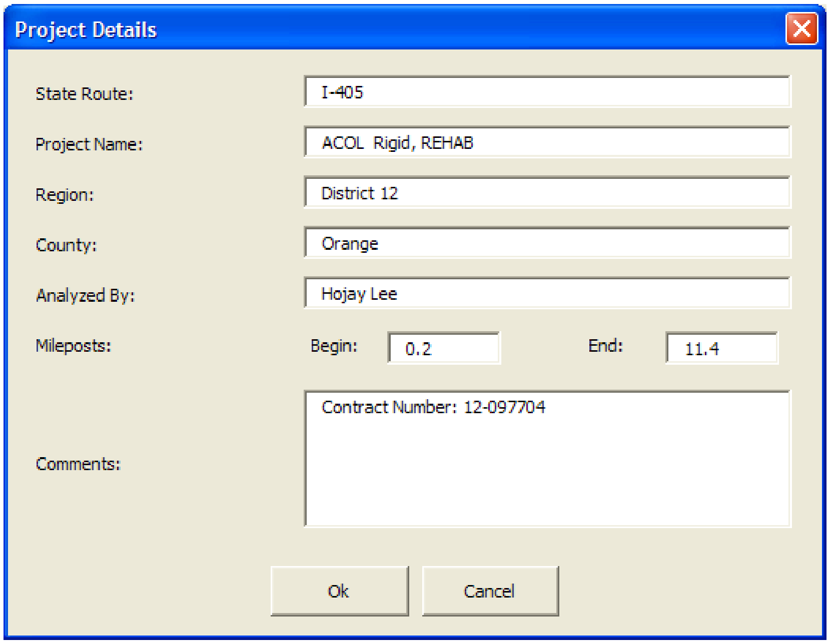


Figure 4. Project Details form.

4.1.2 <u>Analysis Options</u>

The “Analysis Options” form (Figure 5) is used to define the user options that will actually be applied in analyzing the project alternatives. In this sense, this is where you begin the actual analysis. The data inputs and analysis options available on this form are detailed below.

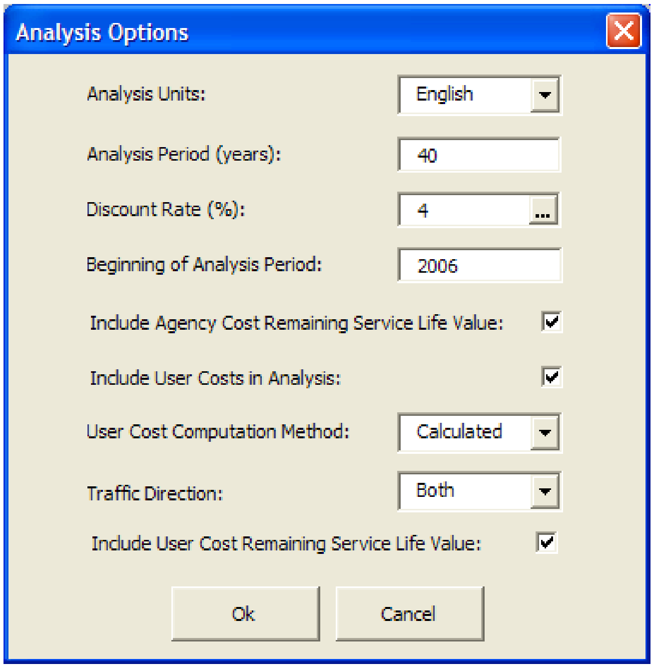


Figure 5. Analysis Options form.

- *Analysis Units*: Select either “English” or “Metric” to set the format in which you want your analysis to appear.
- *Analysis Periods (years)*: Enter an analysis period in years during which project alternatives will be compared. Refer to Table 1 in Section 3.2 to decide on an analysis period appropriate to the design life of each alternative. As noted in that section, you might need to run *RealCost* twice with different analysis periods to compare two alternatives with significantly different design lives: first run the program to calculate the EUAC of an alternative with a particular design life, then run it again for an alternative with a longer design life.

(Note: The Analysis Period in *RealCost* has an expected range of one to forty years. Entering a value greater than forty years will result in the warning message, “Out of Range.” The message,

however, does not signal an error in the input data. The program will still run and correctly calculate the input data: see Appendix 1.) *Discount Rate (%)*: Enter the Caltrans default value of four (4) percent for the deterministic analysis.

- *Beginning of Analysis Period*: Enter the current year or the year in which the project alternative will be undertaken or built.
- *Include Agency Cost Remaining Service Life:* Click the checkbox to have the remaining service life value include a prorated share of agency costs (i.e., salvage value) if the service life of a project alternative extends beyond the analysis period.
- *Include User Costs in Analysis:* Click the checkbox to have *RealCost* include user costs in the analysis and display the calculated user costs results.
- User Cost Computation Method: Select “Calculated” to have *RealCost* calculate user costs based on project-specific input data.
- *Traffic Direction:* Directs *RealCost* to calculate user costs for the “inbound” lanes, the “outbound” lanes, or “both” inbound and outbound lanes. Select the traffic lanes which will be affected by work zone operations.
- *Include User Cost Remaining Service Life:* Click the checkbox to have the remaining service life value include a prorated share of user costs (i.e., salvage value) if the service life of a project alternative extends beyond the analysis period.

Once you have defined all the analysis options, click the “Ok” button to return to the Switchboard or the “Cancel” button to start again.

4.1.3 Traffic Data

The “Traffic Data” form (Figure 6) is used to enter project-specific traffic data that will be used exclusively to calculate work zone user costs in accordance with the method outlined in the FHWA’s *LCCA Technical Bulletin* (1998), “Life-Cycle Cost Analysis in Pavement Design.” Information on traffic data is typically included in the Project Report (PR), the Project Study Report (PSR), or the Plans, Specifications, and Estimate (PS&E). If none of these sources has the data, you can obtain it from the Division of Traffic Operations (TO) Web site at *http://www.dot.ca.gov/hq/traffops/saferesr/trafdata/index.htm* or from a specific location noted in this manual. The traffic data inputs are described below.

The traffic data inputs are described below.

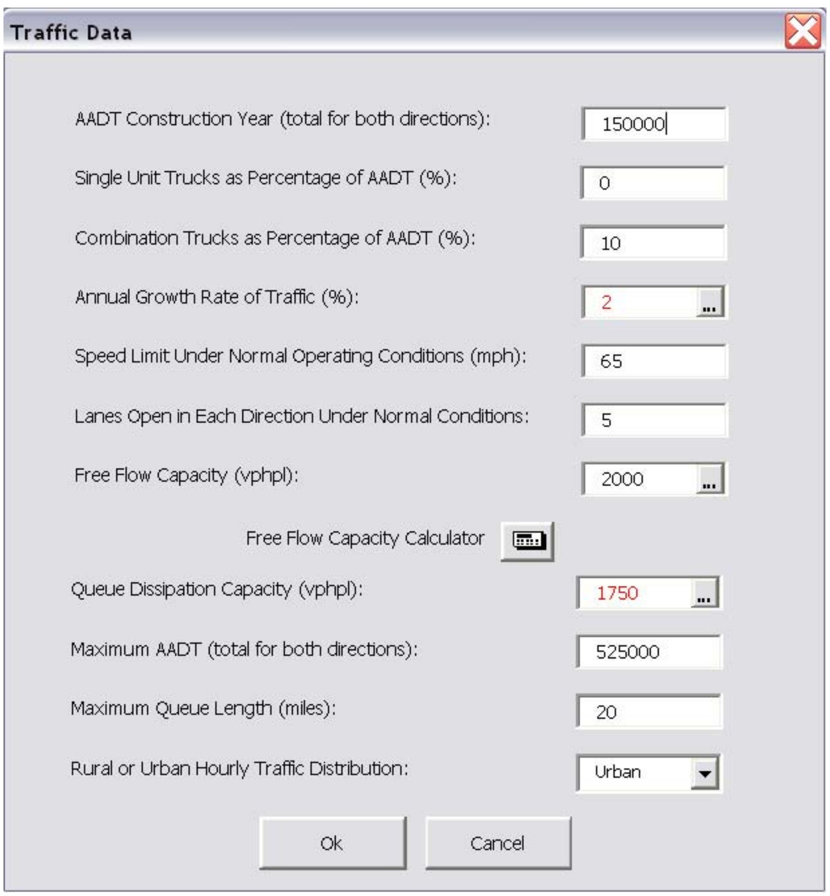


Figure 6. Traffic Data form.

- *AADT Construction Year (total for both directions)*: Enter the annual average daily traffic (for both directions) in the construction year or base year of the analysis.
- *Single Unit Trucks as Percentage of AADT (%):* Enter the percentage of the AADT that is single unit trucks (i.e., commercial trucks with two-axles and four tires or more).
- *Combination Trucks as Percentage of AADT (%):* Enter the percentage of the AADT that is combination trucks (i.e., commercial trucks with three axles or more).
- *Annual Growth Rate of Traffic (%)*: Enter the percentage by which the AADT in both directions will increase each year. If a project-specific rate is not available, refer to Table 6 to determine an approximate growth rate appropriate for the project site location. The annual traffic percentage increases included in the table are based upon the projected state highway traffic volume estimates produced by the Division of Transportation System Information (TSI).

Table 6. Example of State Highway Annual Traffic Growth

Functional Class	Descriptions	2005 AADT			2025 AADT			Annual % Increase				Remarks
		Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Standard Deviation	
1	Rural Principal Arterial - Interstate	11,000	168,000	48,940	21,500	237,000	76,755	0.996%	1.066%	1.027%	0.013%	57 Samples
2	Rural Principal Arterial - Other	1,250	112,500	23,721	1,640	193,000	39,397	0.975%	1.060%	1.024%	0.010%	120 Samples
Rural Sub-total		1,250	168,000	31,843	1,640	237,000	51,428	0.975%	1.066%	1.025%	0.011%	177 Samples
11	Urban Principal Arterial - Interstate	16,800	382,000	192,725	30,700	553,000	273,557	1.005%	1.043%	1.019%	0.006%	119Samples
12	Urban Principal Arterial - Other Freeways or Expressways	880	311,000	96,583	2,000	458,000	143,227	0.958%	1.060%	1.020%	0.012%	158 Samples
14	Urban Principal Arterial - Other	3,300	85,000	28,332	5,460	324,000	48,131	0.995%	1.119%	1.025%	0.015%	121 Samples
Urban Sub-total		880	382,000	104,579	2,000	553,000	153,412	0.958%	1.119%	1.021%	0.012%	398 Samples
Total		880	382,000	82,735	1,640	553,000	122,555	0.958%	1.119%	1.022%	0.013%	575 Samples

- *Speed Limit under Normal Operating Conditions (mph)*: Enter the posted speed limit at the project site location. If a roadway is being newly built, enter an anticipated speed limit.
- *Lanes Open in Each Direction under Normal Conditions*: Enter the number of lanes open to traffic in each direction during normal operating hours. For widening of existing roadway, enter the number of existing lanes, not the future number of lanes. If a roadway is being newly built, enter the designed number of lanes.
- *Free Flow Capacity (vphpl)*: Enter the number of vehicles per hour per lane during normal operating hours. Refer to Table 7 for the recommended values for a typical freeway in a rural and in an urban area. Alternatively, you may click the “Free Flow Capacity Calculator” to open a form that calculates free flow capacities based upon the *Highway Capacity Manual (1994)*, 3rd Ed. To use the calculator, enter the following project-specific information: number of lanes in each direction, lane width, proportion of trucks and buses, upgrade, upgrade length, obstruction on two sides, and distance to obstruction/shoulder width.

Table 7. Traffic Input Values

	Two-Lane Freeways(1) (in rural areas)			Multi-Lane Freeways(1) (in urban areas)		
Type of Terrain	Leveled	Rolling	Mountainous	Leveled	Rolling	Mountainous
Free Flow Capacity (vphpl)	1,620	1,480	1,260	2,170	1,950	1,620
Queue Dissipation Capacity (vphpl)	1,710	1,570	1,330	1,700	1,530	1,270
Maximum AADT (total for both directions)(2)	81,910	74,780	63,700	215,090	193,220	160,560
Work Zone Capacity (vphpl)(3)	1,050	960	820	1,510	1,360	1,130
Work Zone Speed Limit	30 mph (55 mph to 65 mph as normal speed limit)			55 mph (65 mph to 70 mph as normal speed limit)		
Maximum Queue Length(4)	7.0 miles if the estimated maximum queue length is longer than 7.0 miles			5.0 miles if the estimated maximum queue length is longer than 5.0 miles		

(1) 10.0 % and 12.0 % of AADT assmed as truck volume for rural freeways and urban freeways, respectively
(2) 2 lanes for rural freeways and 4 lanes for urban freeways assumed
(3) 1 lane open for rural freeways, two or more lanes open for urban freeways assumed
(4) Based upon the demand-capacity model described in Appendix 3

- *Queue Dissipation Capacity (vphpl*): Enter the vehicles per hour per lane capacity of each lane during queue-dissipation operating conditions. Refer to Table 7 for the recommended values for a typical freeway in a rural and in an urban area.
- *Maximum AADT (total for both directions)*: Enter the maximum AADT in both directions at which the traffic growth will be capped. If traffic grows beyond this value, it will be substituted for the computed future AADT value and future user costs will be calculated based upon it. Refer to Table 7 for the recommended values for a typical freeway in a rural and in an urban area.
- *Maximum Queue Length (miles)*: Enter a practical maximum length of queue in miles. Reasonable maximum queue length could be one or two exits prior to the work zone or an exit that leads to a reasonable alternate route. Queue-related user costs, which are based upon queue length, will be calculated with this value in cases when the

RealCost-calculated queue lengths exceed this value. If a project-specific value is not available, enter five (5) miles for urban freeways and seven (7) miles for rural freeways. *(Note*: Appendix 3 explains briefly the demand-capacity model — queuing theory — that *RealCost* uses in calculating maximum queue length.)

- *Rural or Urban Hourly Traffic Distribution*: Select "Rural" or "Urban" depending on the project site location. Refer to the PR for the roadway classification assigned to the project site. For details on Caltrans' roadway classifications, visit the TSI web site at *http://www.dot.ca.gov/hq/tsip/hpms/Page1.php.*

Once you have entered all the traffic data, click the "Ok" button to return to the Switchboard or the "Cancel" button to start over.

4.1.4 Value of User Time

The "Value of User Time" form (Figure 7) is used to enter the values applied to an hour of user time. The dollar value of use time is typically different for each type of vehicle and is used to calculate user costs associated with delay during work zone operations. Enter $10.46 per hour for passenger cars and $27.83 per hour for both single unit and combination trucks. These dollar values are based upon the Caltrans' Cal-B/C model (2004). Once you have entered the dollar values, click the "Ok" button to return to the Switchboard or the "Cancel" button to start over.

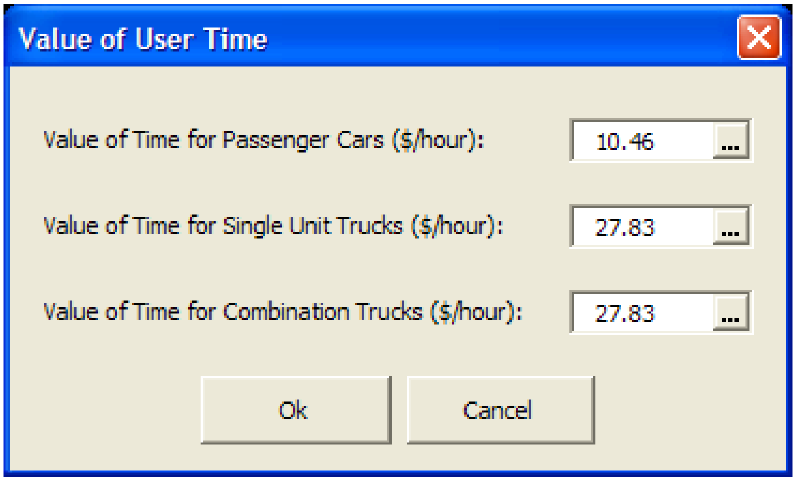
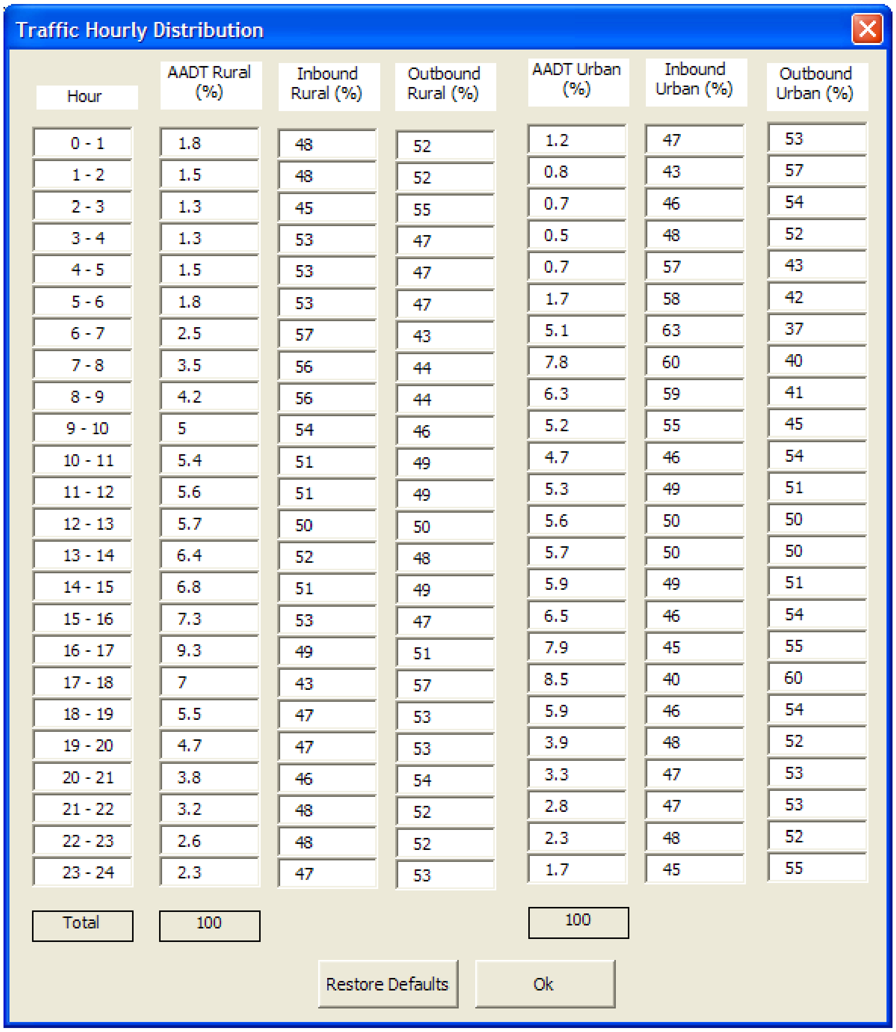


Figure 7. Value of User Time form.

4.1.5 Traffic Hourly Distribution

The Traffic Hourly Distribution form (Figure 8) allows an adjustment to (or restoration of) the default Rural and Urban Traffic hourly distributions which are used in converting AADT to an hourly traffic distribution. If project-specific data are not available, enter the average hourly values, shown in Table 8, which are generated from the Caltrans' traffic counts data (April 2005 data collected by TO) on selected highway locations (a total of forty-two samples). Refer to Appendix 4 for the weekday-only and weekend-only traffic hourly distributions.



Traffic Hourly Distribution

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.8	48	52	1.2	47	53
1 - 2	1.5	48	52	0.8	43	57
2 - 3	1.3	45	55	0.7	46	54
3 - 4	1.3	53	47	0.5	48	52
4 - 5	1.5	53	47	0.7	57	43
5 - 6	1.8	53	47	1.7	58	42
6 - 7	2.5	57	43	5.1	63	37
7 - 8	3.5	56	44	7.8	60	40
8 - 9	4.2	56	44	6.3	59	41
9 - 10	5	54	46	5.2	55	45
10 - 11	5.4	51	49	4.7	46	54
11 - 12	5.6	51	49	5.3	49	51
12 - 13	5.7	50	50	5.6	50	50
13 - 14	6.4	52	48	5.7	50	50
14 - 15	6.8	51	49	5.9	49	51
15 - 16	7.3	53	47	6.5	46	54
16 - 17	9.3	49	51	7.9	45	55
17 - 18	7	43	57	8.5	40	60
18 - 19	5.5	47	53	5.9	46	54
19 - 20	4.7	47	53	3.9	48	52
20 - 21	3.8	46	54	3.3	47	53
21 - 22	3.2	48	52	2.8	47	53
22 - 23	2.6	48	52	2.3	48	52
23 - 24	2.3	47	53	1.7	45	55
Total	100			100		

Restore Defaults
Ok

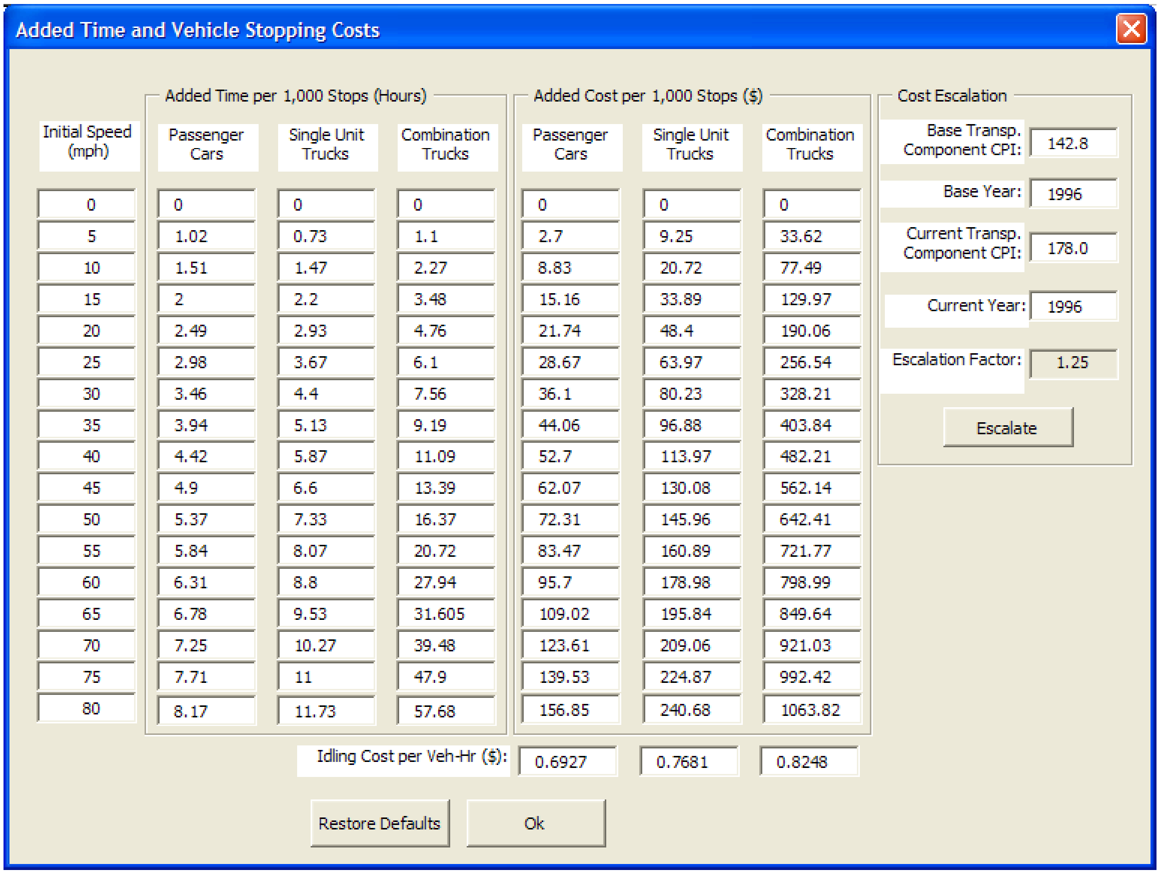
Figure 8.Traffic Hourly Distribution form.

Table 8. Average State Highway Traffic Hourly Distribution

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.70	48.5	51.5	1.2	47.9	52.1
1 - 2	1.39	51.3	48.7	0.8	49.0	51.0
2 - 3	1.31	52.4	47.6	0.7	50.4	49.6
3 - 4	1.52	58.0	42.0	0.8	55.5	44.5
4 - 5	2.00	60.0	40.0	1.4	59.9	40.1
5 - 6	3.06	57.9	42.1	2.6	58.9	41.1
6 - 7	4.24	56.3	43.7	4.3	56.9	43.1
7 - 8	4.81	55.7	44.3	5.3	55.9	44.1
8 - 9	4.91	54.3	45.7	5.4	54.5	45.5
9 - 10	5.14	53.3	46.7	5.5	52.9	47.1
10 - 11	5.45	52.2	47.8	5.7	51.0	49.0
11 - 12	5.73	51.0	49.0	6.1	49.8	50.2
12 - 13	5.90	50.9	49.1	6.3	49.0	51.0
13 - 14	5.98	51.3	48.7	6.4	48.4	51.6
14 - 15	6.27	50.9	49.1	6.7	46.8	53.2
15 - 16	6.66	50.1	49.9	7.0	45.6	54.4
16 - 17	6.73	49.0	51.0	6.9	44.7	55.3
17 - 18	6.35	47.3	52.7	6.5	44.8	55.2
18 - 19	5.38	47.3	52.7	5.4	45.5	54.5
19 - 20	4.44	46.3	53.7	4.4	46.0	54.0
20 - 21	3.70	47.3	52.7	3.7	46.4	53.6
21 - 22	3.10	47.6	52.4	3.1	46.9	53.1
22 - 23	2.46	48.1	51.9	2.3	47.9	52.1
23 - 24	1.78	47.5	52.5	1.5	46.3	53.7
	100.0			100.0		

4.1.6 Added Time and Vehicle Stopping Costs

The “Added Time and Vehicle Stopping Costs” form (Figure 9) is used to adjust the default values for added time and added cost per 1,000 stops. The default values are based upon the NCHRP (National Cooperative Highway Research Program) Study 133 (1996), *Procedures for Estimating Highway User Costs, Air Pollution, and Noise Effects.* These values are used to calculate user delay and vehicle costs due to speed changes that occur during work zone operations. The “Idling Cost per Veh-Hr ($)” is used to calculate the additional vehicle operating costs that result from a traffic queue under stop-and-go conditions.



Added Time and Vehicle Stopping Costs

Initial Speed (mph)	Added Time per 1,000 Stops (Hours): Passenger Cars	Single Unit Trucks	Combination Trucks	Added Cost per 1,000 Stops ($): Passenger Cars	Single Unit Trucks	Combination Trucks
0	0	0	0	0	0	0
5	1.02	0.73	1.1	2.7	9.25	33.62
10	1.51	1.47	2.27	8.83	20.72	77.49
15	2	2.2	3.48	15.16	33.89	129.97
20	2.49	2.93	4.76	21.74	48.4	190.06
25	2.98	3.67	6.1	28.67	63.97	256.54
30	3.46	4.4	7.56	36.1	80.23	328.21
35	3.94	5.13	9.19	44.06	96.88	403.84
40	4.42	5.87	11.09	52.7	113.97	482.21
45	4.9	6.6	13.39	62.07	130.08	562.14
50	5.37	7.33	16.37	72.31	145.96	642.41
55	5.84	8.07	20.72	83.47	160.89	721.77
60	6.31	8.8	27.94	95.7	178.98	798.99
65	6.78	9.53	31.605	109.02	195.84	849.64
70	7.25	10.27	39.48	123.61	209.06	921.03
75	7.71	11	47.9	139.53	224.87	992.42
80	8.17	11.73	57.68	156.85	240.68	1063.82
			Idling Cost per Veh-Hr ($):	0.6927	0.7681	0.8248

Cost Escalation

Base Transp. Component CPI: 142.8

Base Year: 1996

Current Transp. Component CPI: 178.0

Current Year: 1996

Escalation Factor: 1.25

Escalate

Restore Defaults Ok

Figure 9. Added Time and Vehicle Stopping Costs form.

The default values, expressed in 1996 dollars, can be adjusted to the current year dollar amounts by entering the transportation-component CPI (consumer price index) of the base (1996) and current years. Table 9 shows the “Consumer Price Indexes for All Urban Consumers” for all items, and the transportation component in the U.S. and the State of California. Since the statewide transportation component CPI’s are not currently available, the U.S. transportation-component CPI (which appears in bold text) can be used. For example, for a 2006 year analysis, enter 2006 and 178.0 as the “Current Year” and “Current Transp. Component CPI” values, respectively; then click the “Escalate” button. The program will update the cost data. To get back to the default values, click the “Restore Defaults” button.

Table 9. Consumer Price Indexes for All Urban Consumers

Year	All Items		Transporation		
	US	California	US	LA CMSA*	SF CMSA*
1996	156.9	157.1	**143.0**	144.3	133.5
1997	160.5	160.5	**144.3**	145.2	133.6
1998	163.0	163.7	**141.6**	142.6	132.0
1999	166.6	168.5	**144.4**	146.8	135.8
2000	172.2	174.7	**153.3**	154.2	143.1
2001	177.1	181.8	**154.3**	155.3	143.7
2002	179.9	186.1	**152.9**	154.5	141.0
2003	184.0	190.4	**157.6**	160.3	145.0
2004	188.9	195.3	**163.1**	166.5	149.6
2005	195.6	202.9	**175.2**	176.2	157.3
2006	201.9	210.3	**178.0**	177.1	159.3
2007	206.7	216.6	**177.2**	171.6	156.2
2008	211.8	223.3	**177.9**	167.3	154.1

Source: California Department of Finance, Economic Research Unit
http://www.dof.ca.gov/HTML/FS_DATA/LatestEconData/FS_Price.htm

* LA CMSA: includes counties of Los Angeles, Orange, Riverside, San Bernadino, & Ventura

* SF CMSA: includes counties of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, & Sonoma

4.1.7 Saving and Loading Project-Level Inputs

The “Save Project-Level Inputs” and “Open Project-Level Inputs” buttons are used to save and to retrieve project-level inputs. The user can save the project-level inputs at a preferred location under a user-specified name, and the file will be automatically saved with the *.LCC extension.

4.2 Alternative-Level Inputs

The “Alternative 1” (shown in Figure 10) and “Alternative 2” forms are identical and are used to enter the alternative-level inputs that define the differences between projects that are being considered (i.e., the agency costs and work zone specifics for component M&R activities of each alternative). Each project alternative can be composed of up to seven major M&R activities (“Initial Construction” and “Rehabilitation 1” through “Rehabilitation 6”) The data describing these activities must be entered in sequence for each of the two project alternatives being compared. For example, “Initial Construction” precedes “Rehabilitation 1” and “Rehabilitation 3” precedes “Rehabilitation 4.” The data inputs required under each activity tab on the form are described below.

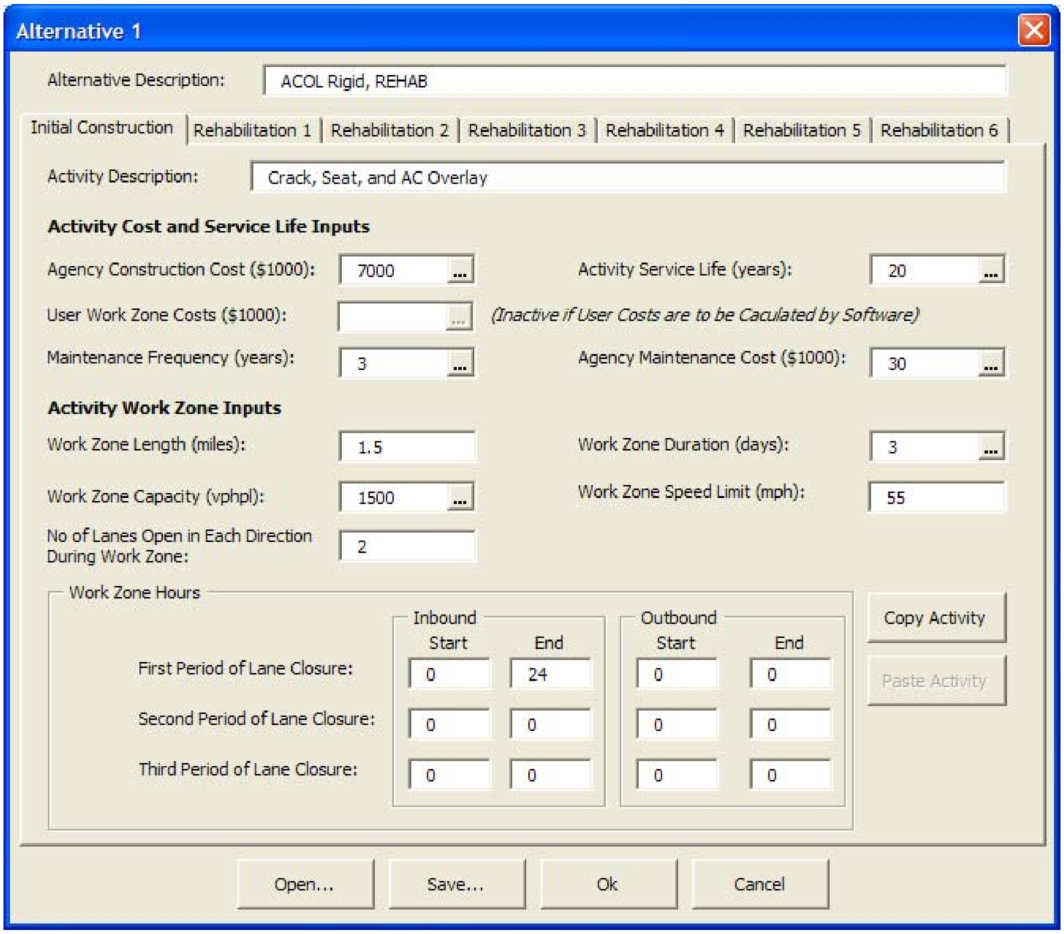


Figure 10. Alternative 1 form (which is identical to the Alternative 2 form).

- *Alternative Description*: Enter a description for a project alternative. For example, “ACOL FLEX (5-Year CAPM)” or “Mill & Replace AC (10-Year Rehabilitation).”
- *Activity Description*: Enter a description for a component M&R activity of each project alternative. *(Note:* for Initial Construction, use the same description entered for Alternative Description.)
- *Agency Construction Cost ($1000)*: Under the “Initial Construction” tab, enter the total initial costs in thousands of dollars (engineer’s estimate plus project support costs) for a project alternative (as discussed in Section 3.5.1.). For each component M&R activity of a project alternative, enter the total rehabilitation costs in thousands of dollars for the activity (see Section 3.5.3).
- *Activity Service Life (years):* Enter the service life of a project alternative (under “Initial Construction” tab) or that of a component M&R activity to be followed (under each “Rehabilitation” tab). Refer to Appendix 2 for a pavement M&R schedule applicable for project alternatives and service lives estimated for component M&R activities.
- *User Work Zone Costs ($1000):* This field will be inaccessible since the User Cost Computation Method on the Analysis Options form is set to be calculated as the default.
- *Maintenance Frequency (years):* Refers to the cyclical frequency of preventive or corrective maintenance to follow Initial Construction or after each component M&R activity. Enter one (1) year as “Maintenance Frequency,” since the EUAC of this maintenance will be entered as “Agency Maintenance Cost” in the next step.

- *Agency Maintenance Cost ($1000):* As discussed in Section 3.5.2, this cost includes the costs of preventive or corrective maintenance to preserve or to extend the service life of the Initial Construction or of each component M&R activity. Refer to Appendix 2 for an applicable pavement M&R schedule and EUAC.
- *Work Zone Length (miles*): This refers to the length in miles of the work zone being considered for Initial Construction or for each component M&R activity. The work zone length should be based on what is allowed from traffic handling plans, traffic management plans, or historical experience, and it should be measured is measured from the beginning to end of the reduced speed area where the work zone speed limit is in effect. This information can be obtained from the District TO.
- *Work Zone Duration (days):* This refers to the number of days during which the work zone will be affecting traffic. For example, if the work zone is in effect five days a week for four weeks, the value would be twenty. The estimated work zone duration for Initial Construction can be obtained from the District Construction. To estimate work zone durations for future component M&R activities, refer to Table 10 and Table 11. These tables show estimates of the amount of work (lane-mile per closure) that can be completed under different construction windows and lane closure tactics for typical M&R projects. Table 10 contains estimates for flexible/rigid pavements and Table 11 contains estimates for rigid pavements only. These production rates are estimated with *CA4PRS* (Construction Analysis for Pavement Rehabilitation Strategies), and assume typical working conditions and resource configurations observed in past projects. The latest version of *CA4PRS* and its user manual can be

obtained from the Division of Research and Innovation (DRI) Web site at

http://www.dot.ca.gov/research/roadway/ca4prs/ca4prs.htm.

Table 10. Productivity Estimates of Typical Rehabilitation Strategies for Flexible/Rigid Pavements

Strategy Type	Strategy Alternative	Description	Lane Closure Tactic (Working Method)	Average Lane-mile Completed Per Closure			
				Weekday Partial Closure (10 hour/day Operation)	Weekday Continuous Closure (24 hour/day Operation)	Weekday Continuous Closure (16 hour/day Operation)	Weekend 55-Hour Extended Closure
5-Yr CAPM	ACOL FLEX	60 mm DGAC	Two-lane Closure (Single-Lane Paving)	1.2	3.9	2.5	13.2
			Four-lane Closure (Double-lane Paving)	N/A	4.9	3.2	16.8
		75 mm DGAC	Two-lane Closure (Single-Lane Paving)	0.8	3.0	2.0	10.6
			Four-lane Closure (Double-lane Paving)	N/A	3.8	2.6	13.5
	MILL & REPL AC	30 mm Mill, 30 mm OGAC	Two-lane Closure (Single-Lane Paving)	1.3	3.9	2.4	11.9
			Four-lane Closure (Double-lane Paving)	N/A	5.0	3.1	15.2
		30 mm Mill, 75 mm DGAC	Two-lane Closure (Single-Lane Paving)	0.5	2.1	1.4	7.1
			Four-lane Closure (Double-lane Paving)	N/A	2.6	1.8	9.1
	RAC	50 mm RAC-G	Two-lane Closure (Single-Lane Paving)	1.0	3.3	2.1	11.1
			Four-lane Closure (Double-lane Paving)	N/A	4.2	2.7	14.1
		60 mm RAC-G	Two-lane Closure (Single-Lane Paving)	0.8	2.7	1.8	9.2
			Four-lane Closure (Double-lane Paving)	N/A	3.5	2.2	11.8
10-Yr REHAB.	ACOL FLEX	135 mm DGAC (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.5	1.7	0.9	5.8
			Four-lane Closure (Double-lane Paving)	N/A	2.2	1.1	7.4
		165 mm DGAC (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.1	1.3	0.6	4.8
			Four-lane Closure (Double-lane Paving)	N/A	1.7	0.7	6.1
	MILL & REPL AC	30 mm Mill, 150 mm DGAC (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.1	1.2	0.8	4.2
			Four-lane Closure (Double-lane Paving)	N/A	1.5	0.7	5.4
		105 mm Mill, 30 mm RAC-O + 75 mm DGAC (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.2	1.0	0.6	3.1
			Four-lane Closure (Double-lane Paving)	N/A	1.2	0.4	4.0
20-Yr REHAB.	MILL & REPL AC	195 mm Mill, 30 mm RAC-O +165 mm DGAC (in 3 lifts)	Two-lane Closure (Single-Lane Paving)	N/A	0.6	0.2	1.8
			Four-lane Closure (Double-lane Paving)	N/A	0.7	0.3	2.2
40-Yr REHAB.	ACOL RIGID	30 mm RAC-O + 205 mm DGAC (in 4 lifts)	Two-lane Closure (Single-Lane Paving)	N/A	0.3	N/A	3.1
			Four-lane Closure (Double-lane Paving)	N/A	0.4	N/A	4.0

Table 11. Productivity Estimates of Typical Rehabilitation Strategies for Rigid Pavements Only

Strategy Type	Strategy Alternative	Description	Lane Closure Tactic (Working Method)	Average Lane-mile Completed Per Closure			
				Weekday Partial Closure (10 hour/day Operation)	Weekday Continuous Closure (24 hour/day Operation)	Weekday Continuous Closure (16 hour/day Operation)	Weekend 55-Hour Extended Closure
5-Yr CAPM	ACOL RIGID	30 mm OGAC + 45 mm RAC-G (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.9	2.6	1.6	8.6
			Four-lane Closure (Double-lane Paving)	N/A	3.3	2.0	10.8
	GRINDING	Profile grinding	Two-lane Closure (Single-Lane Paving)	2.3	5.8	3.8	N/A
			Four-lane Closure (Double-lane Paving)	N/A	N/A	N/A	N/A
10-Yr REHAB.	ACOL RIGID	30 mm OGAC + 75 mm DGAC (in 2 lifts)	Two-lane Closure (Single-Lane Paving)	0.8	2.2	1.1	7.5
			Four-lane Closure (Double-lane Paving)	N/A	2.9	1.6	9.5
	CPR	5% slab replacement with profile grinding (230 mm new slab with 4-Hr FSHCC)	Two-lane Closure (Single-Lane Paving)	1.1	6.1	3.6	N/A
			Four-lane Closure (Double-lane Paving)	N/A	N/A	N/A	N/A
		5% slab replacement with profile grinding (230 mm new slab with 12-Hr RSC)	Two-lane Closure (Single-Lane Paving)	N/A	2.9	0.7	N/A
			Four-lane Closure (Double-lane Paving)	N/A	N/A	N/A	N/A
20-Yr REHAB.	PCC OVERLAY	205 mm new slab + 25 mm DGAC interlayer (with 12-Hr RSC)	Two-lane Closure (Single-Lane Paving)	N/A	0.26	0.07	0.91
			Four-lane Closure (Double-lane Paving)	N/A	0.34	0.09	1.17
40-Yr REHAB.	CPR	Lane replacement with profile grinding (290 mm new slab with 12-Hr RSC + 150 mm new treated AC base)	Two-lane Closure (Single-Lane Paving)	N/A	0.14	0.04	0.48
			Four-lane Closure (Double-lane Paving)	N/A	0.18	0.04	0.62

- *Work Zone Capacity (vphpl):* Enter the vehicular capacity of one lane of the work zone for one hour. Refer to Table 7 for the recommended values for a typical freeway in rural and urban areas.
- *Work Zone Speed Limit (mph):* Enter the vehicular capacity of one lane of the work zone for one hour. Refer to Table 7 for the recommended values for a typical freeway in rural and urban areas.
- *No of Lanes Open in Each Direction During Work Zone:* Enter the number of lanes open in the work zone area when the work zone is in effect. The number of lanes open applies to each direction. This information can be obtained from the District TO or the Traffic Management Plan.

- *Work Zone Hours:* Enter the work zone hours (using a twenty-four-hour clock) during which the work zone is in effect. Work zone timing can be modeled separately for inbound and outbound traffic for up to three separate periods for each day. During these hours capacity is limited to the work zone capacity. Work zone hours can be obtained from the District TO or the Traffic Management Plan.

Once you have entered all the alternative-level inputs to the Alternative 1 or Alternative 2 forms, click the “Ok” button to return to the Switchboard or “Cancel” button to start over.

Note: make sure to provide the minimal information in all six “Rehabilitation” tabs to avoid an error message. *No. of Lanes Open in Each Direction during Work Zone*, *Work Zone Speed Limit*, and *Work Zone Capacity* are the minimal inputs required; zero can be entered in the remaining input fields.

4.3 Input Warnings

To see list of missing or potentially erroneous data, click the “Show Warnings” button in the Switchboard to have *RealCost* identify and display a list of potential problems (Figure 11). It is recommended that you verify your inputs by clicking this button before running the analysis.

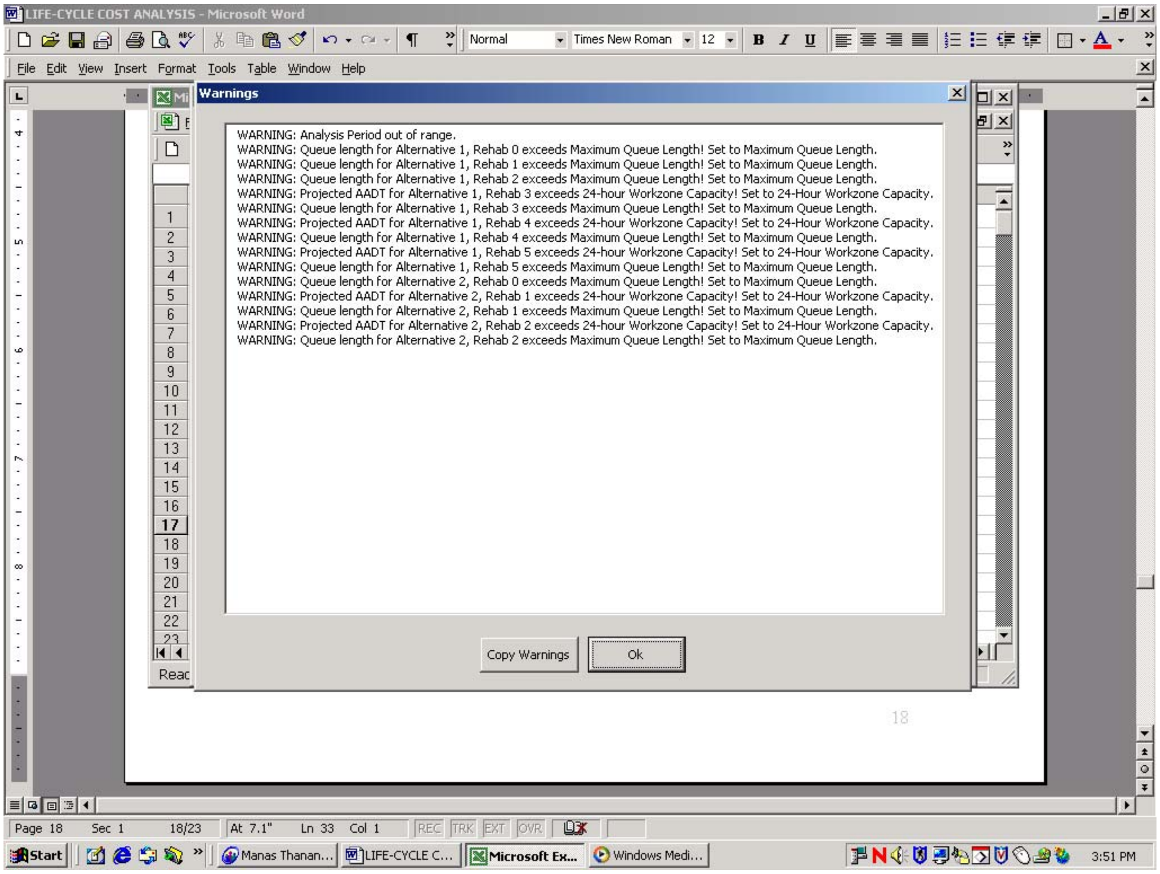


Figure 11. Input Warnings.

4.4 Simulation and Outputs

The "Simulation and Outputs" section of the Switchboard is where deterministic life-cycle costs and simulations of probabilistic life-cycle costs are performed.

- *Deterministic Results:* Click this button to have *RealCost* calculate and display deterministic present values (PV) for both agency and user costs based upon the deterministic inputs. The Deterministic Results form (Figure 12) provides a direct link ("Go to Worksheet" button) to the Deterministic Results *Excel* worksheet that contains all the information needed to investigate deterministic results.

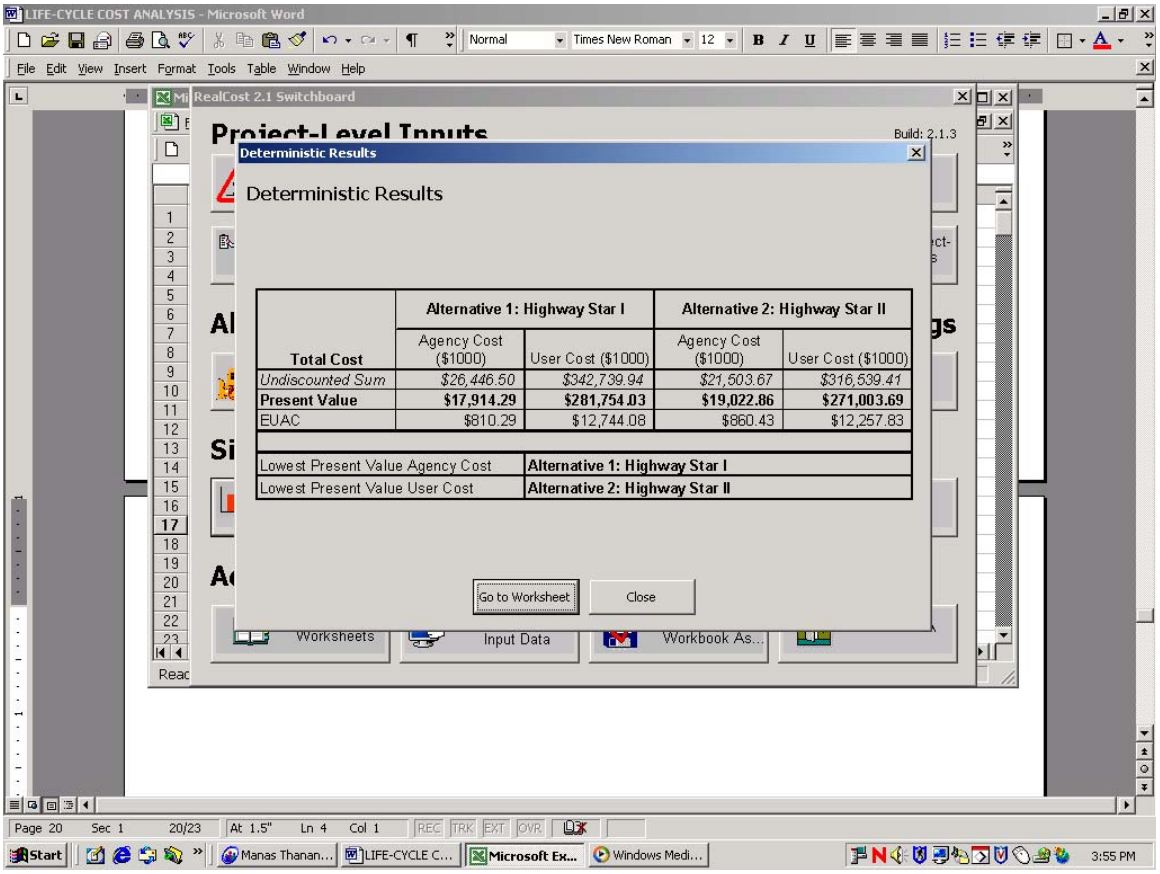
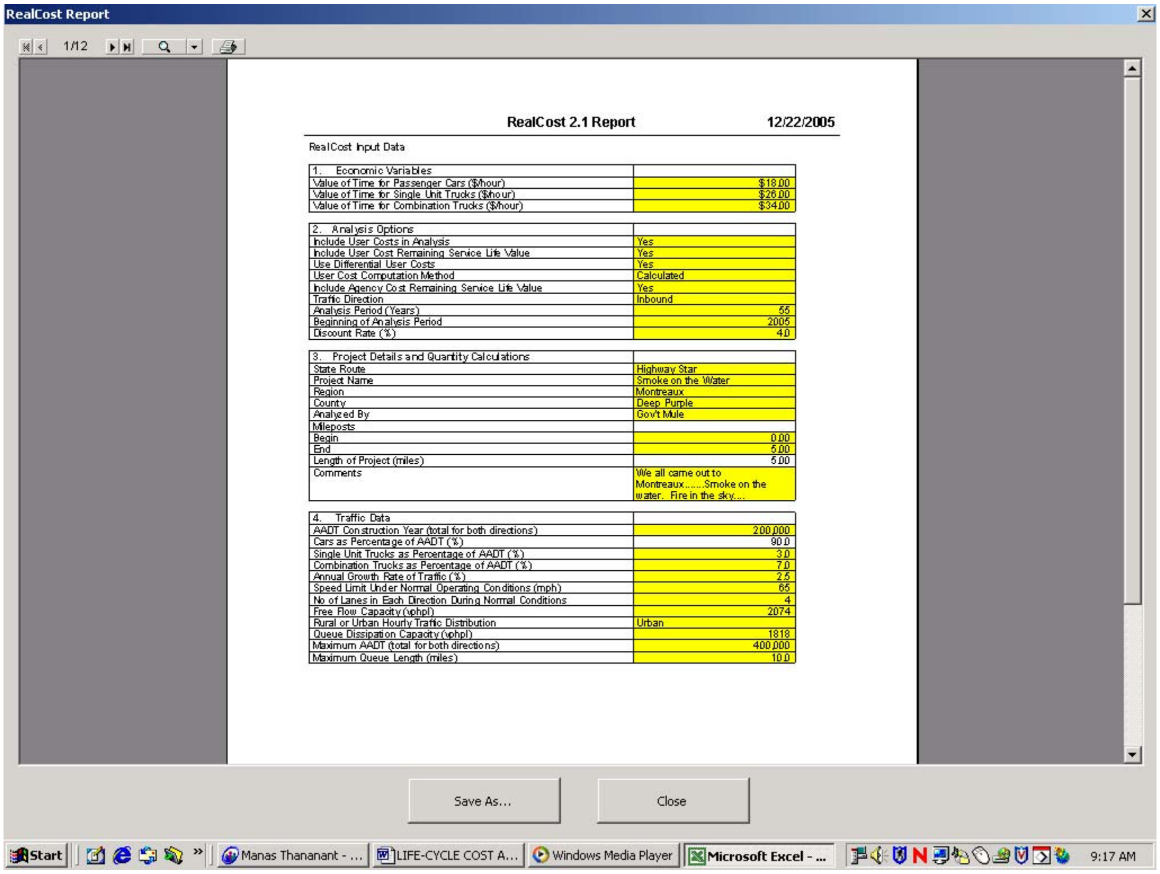


Figure 12. Deterministic Results form.

- *Simulation*: Clicking this button will initiate Monte Carlo simulation of probabilistic inputs. At present it is not being used.
- *Probabilistic Results*: Clicking this button will display probabilistic results. At present it is not being used.
- *Reports*: Click this button to have *RealCost* produce a twelve-page report (Figure 13) that shows inputs and results. The last two pages include results of the probabilistic analysis, and they will be blank if no probabilistic inputs are entered.



RealCost 2.1 Report 12/22/2005

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$18.00
Value of Time for Single Unit Trucks ($/hour)	$26.00
Value of Time for Combination Trucks ($/hour)	$34.00
2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Inbound
Analysis Period (Years)	55
Beginning of Analysis Period	2005
Discount Rate (%)	4.0
3. Project Details and Quantity Calculations	
State Route	Highway Star
Project Name	Smoke on the Water
Region	Montreaux
County	Deep Purple
Analyzed By	Gov't Mule
Mileposts	
Begin	0.00
End	5.00
Length of Project (miles)	5.00
Comments	We all came out to Montreaux.......Smoke on the water. Fire in the sky....
4. Traffic Data	
AADT Construction Year (total for both directions)	200,000
Cars as Percentage of AADT (%)	90.0
Single Unit Trucks as Percentage of AADT (%)	3.0
Combination Trucks as Percentage of AADT (%)	7.0
Annual Growth Rate of Traffic (%)	2.5
Speed Limit Under Normal Operating Conditions (mph)	65
No of Lanes in Each Direction During Normal Conditions	4
Free Flow Capacity (vphpl)	2074
Rural or Urban Hourly Traffic Distribution	Urban
Queue Dissipation Capacity (vphpl)	1818
Maximum AADT (total for both directions)	400,000
Maximum Queue Length (miles)	10.0

Figure 13. *RealCost* Report.

4.5 Administrative Functions

The *Administrative Functions* section of the Switchboard allows the user to save, clear, and retrieve data, and to close the Switchboard or *RealCost*.

- *Go to Worksheets*: Clicking this button will allow direct access to any input or result worksheets.
- *Clear Input Data:* Clicking this button will clear from the software project-level inputs, alternative-level inputs, and results.
- *Save LCCA Workbook As..:* Clicking this button allows you to save the entire Excel workbook, including all inputs and results worksheets, under a name you specify.

- *Exit LCCA:* Clicking this button will close *RealCost.*

5.0 EXAMPLES OF LCCA

5.1 Example One

This is a hypothetical project that involves the removal of an existing portland cement concrete (PCC) pavement and its replacement with either a new asphalt concrete (AC) or PCC pavement. The roadway has four lanes in each direction with 6-ft. wide right and left shoulders. The following is the short description of the project.

5.1.1 Alternative 1: Full-Depth AC Replacement

Alternative 1 is a forty-year rehabilitation that involves removal of existing PCC slab (12-in.) and cement-treated base (6.5-in.) and their replacement with AC (12-in.) on top of AC base (6.5-in.).

a. Initial construction cost is estimated at $12,686,000.

b. Future CAPM's: 2-inch ACOL ($2,777,000) or 2-inch mill and replace AC ($3,409,000) alternating every 9.3 years.

c. No in-between maintenance is assumed.

5.1.2 Alternative 2: Full-depth PCC Replacement

Alternative 2 is also a forty-year rehabilitation involving removal of both existing PCC slab (12-in.) and cement-treated base (6.5-in.) and replacement with PCC (12-inch) on top of AC base (6.5-inch).

a. Initial construction cost is estimated at $18,249,000.

b. Future rehabilitations: random slab replacements with diamond grinding and joint resealing ($2,441,000) every fifteen years.

c. No in-between maintenance is assumed.

Figure 14 shows a typical cross section of the project alternatives.

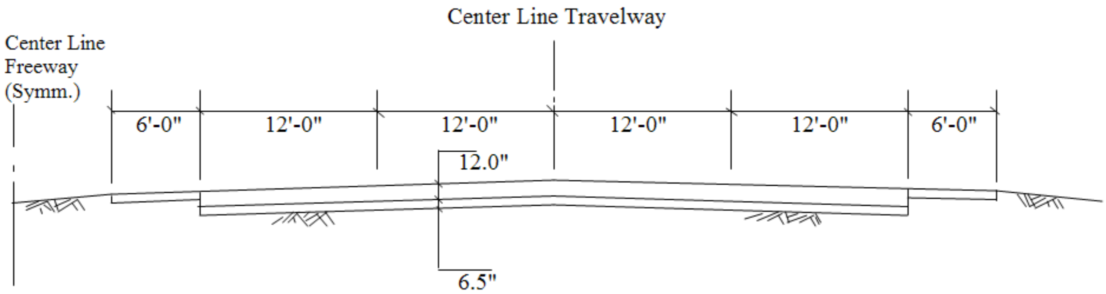


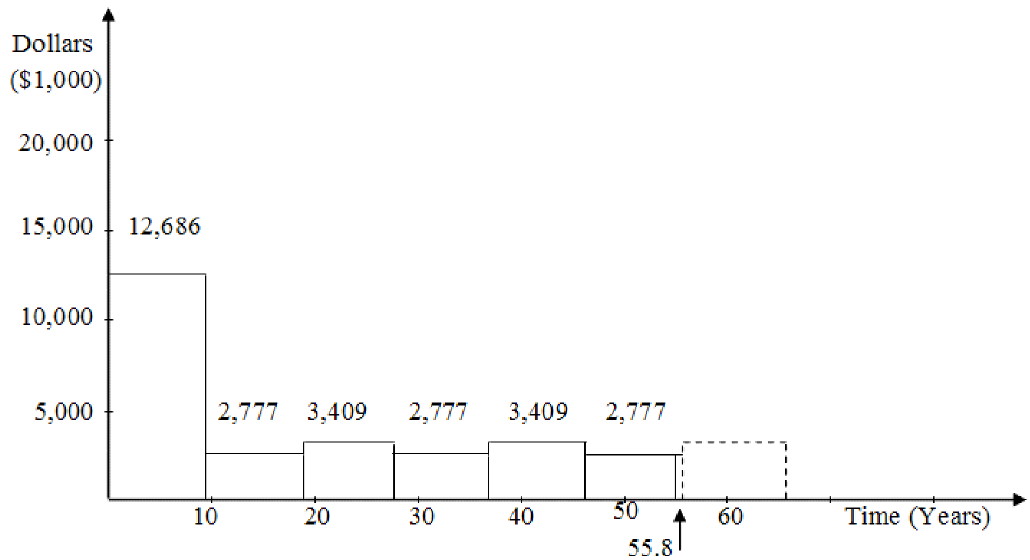
Figure 14. Typical cross section of project alternatives (Example One).

Figure 15 shows the costs of initial-construction/rehabilitations versus time for Alternatives 1 and 2, respectively. It is recommended that the cost-versus-time diagrams of competing alternatives to be drawn to help visualize the analysis.

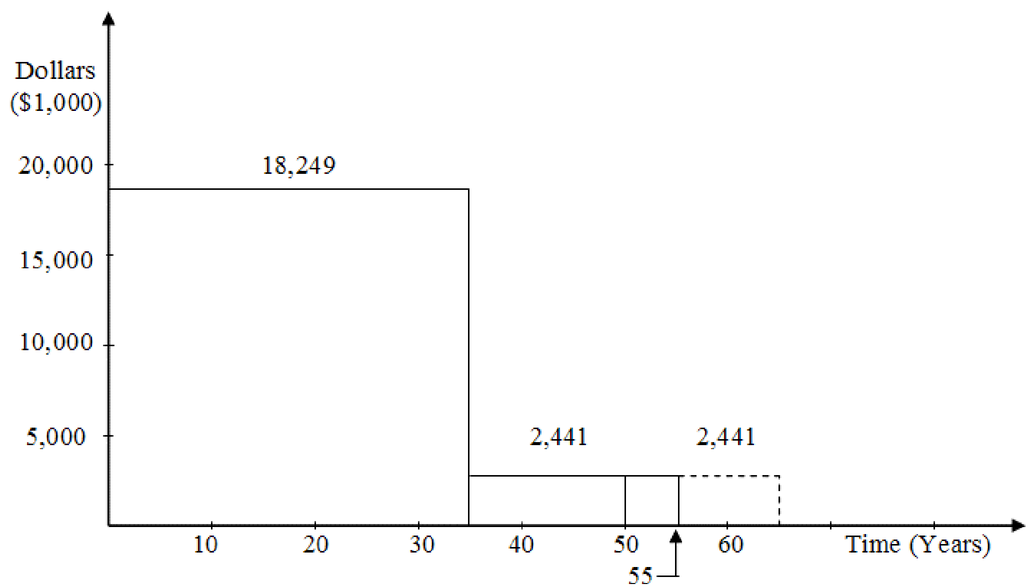
5.1.3 Results of the Example

Figure 16 shows the first page of the twelve-page report. As noted earlier, you only need to print the first ten pages of the page report. Figure 17 shows the tenth page with the deterministic results of the two alternatives.

As the results show, the PV and EUCA of the agency costs for Alternative 1 are less than those for Alternative 2: $17,914,290 (PV #1) and $810,290 (EUAC #1) versus $19,022,860 (PV #2) and $860,430 (EUAC #2), respectively. However, the PV and EUAC of the user costs for Alternative 1 are higher than those for Alternative 2: $281,754,030 (PV #1) and $12,744,080 (EUAC #1) versus $271,003,690 (PV #2) and $12,257,830 (EUAC #2), respectively.



Alternative 1



Alternative 2

Figure 15. Cost vs. Time diagrams of project alternatives (Example One).

RealCost 2.1 Report **12/22/2005**

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$18.00
Value of Time for Single Unit Trucks ($/hour)	$26.00
Value of Time for Combination Trucks ($/hour)	$34.00

2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Inbound
Analysis Period (Years)	55
Beginning of Analysis Period	2005
Discount Rate (%)	4.0

3. Project Details and Quantity Calculations	
State Route	Highway Star
Project Name	Smoke on the Water
Region	Montreaux
County	Deep Purple
Analyzed By	Gov't Mule
Mileposts	
Begin	0.00
End	5.00
Length of Project (miles)	5.00
Comments	We all came out to Montreaux.......Smoke on the water. Fire in the sky....

4. Traffic Data	
AADT Construction Year (total for both directions)	200,000
Cars as Percentage of AADT (%)	90.0
Single Unit Trucks as Percentage of AADT (%)	3.0
Combination Trucks as Percentage of AADT (%)	7.0
Annual Growth Rate of Traffic (%)	2.5
Speed Limit Under Normal Operating Conditions (mph)	65
No of Lanes in Each Direction During Normal Conditions	4
Free Flow Capacity (vphpl)	2074
Rural or Urban Hourly Traffic Distribution	Urban
Queue Dissipation Capacity (vphpl)	1818
Maximum AADT (total for both directions)	400,000
Maximum Queue Length (miles)	10.0

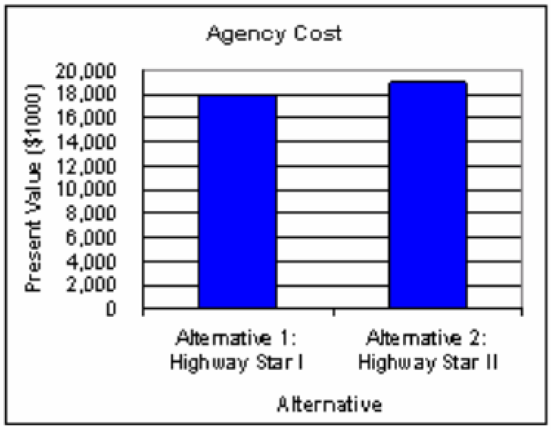
Save As... Close

Figure 16. *RealCost* Report (Example One).

RealCost 2.1 Report **12/22/2005**

Deterministic Results

Total Cost	Alternative 1: Highway Star I		Alternative 2: Highway Star II	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	$26,446.50	$342,739.94	$21,503.67	$316,539.41
Present Value	$17,914.29	$281,754.03	$19,022.86	$271,003.69
EUAC	$810.29	$12,744.08	$860.43	$12,257.83



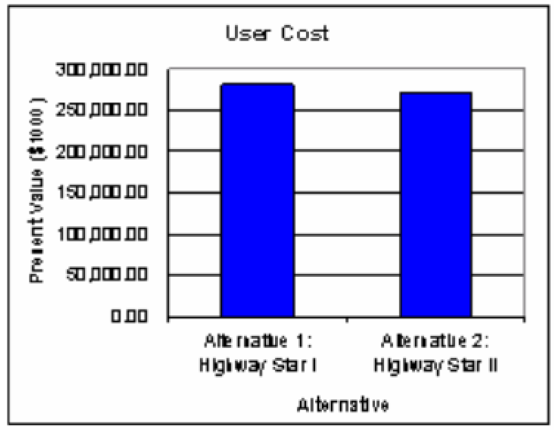


Figure 17. *RealCost* Deterministic Results (Example One).

Comparison of the results shows that the agency cost for Alternative 1 is 6.19 percent less than it is for Alternative 2, while the user cost for Alternative 1 is 3.97 percent more than it is for Alternative 2. Since the difference between the alternatives is within 10 percent either alternative would be appropriate. When choosing a preferred alternative, other factors (such as safety and air pollution, and non-user and business impacts resulting from reduced or restricted traffic) should be considered.

5.2 Example Two

This example was an actual project with two lanes in each direction, but some of the information has been modified for a fair comparison. The following is the short description of the project.

a. Project length is 10 miles.

b. AADT in the construction year is 20,000 for both directions.

c. Single-unit trucks as a percentage of AADT is 17 percent.

d. Combination trucks as a percentage of AADT is 16 percent.

e. Maximum AADT is 100,000 for both directions.

5.2.1 Alternative 1: Mill and Replace AC (5-year CAPM)

Alternative 1 is a five-year CAPM, which involves milling 1-inch of the existing pavement and replacing it with 1-inch of RAC-G.

a. Initial construction cost is estimated at $5,035,380.

b. No in-between maintenance is assumed.

5.2.2. Alternative 2

Alternative 2 is a 10-year CAPM, which involves milling 2-inch of the existing pavement and replacing it with 2-inch of RAC-G.

a. Initial construction cost is estimated at $7,709,390.

b. Maintenance cost is estimated at $200,000 for every 5 years.

Figure 18 shows a typical cross section of the existing pavement.

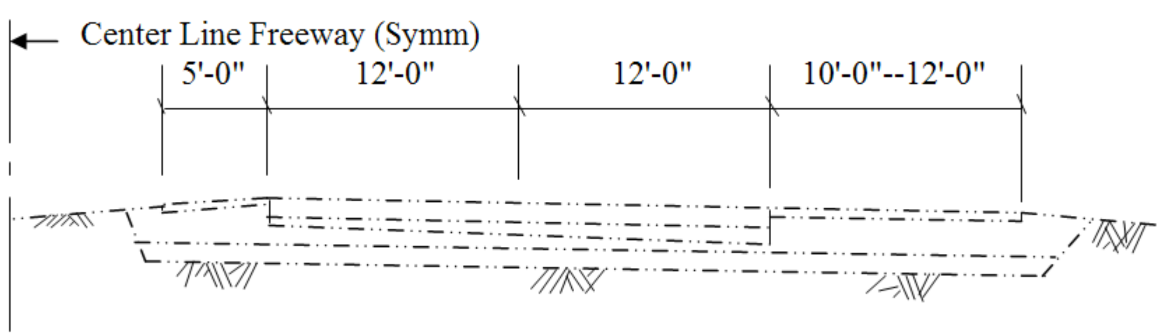


Figure 18. Existing typical cross section (Example Two).

Figure 19 shows the cost-versus-time diagrams for Alternatives 1 and 2, respectively.

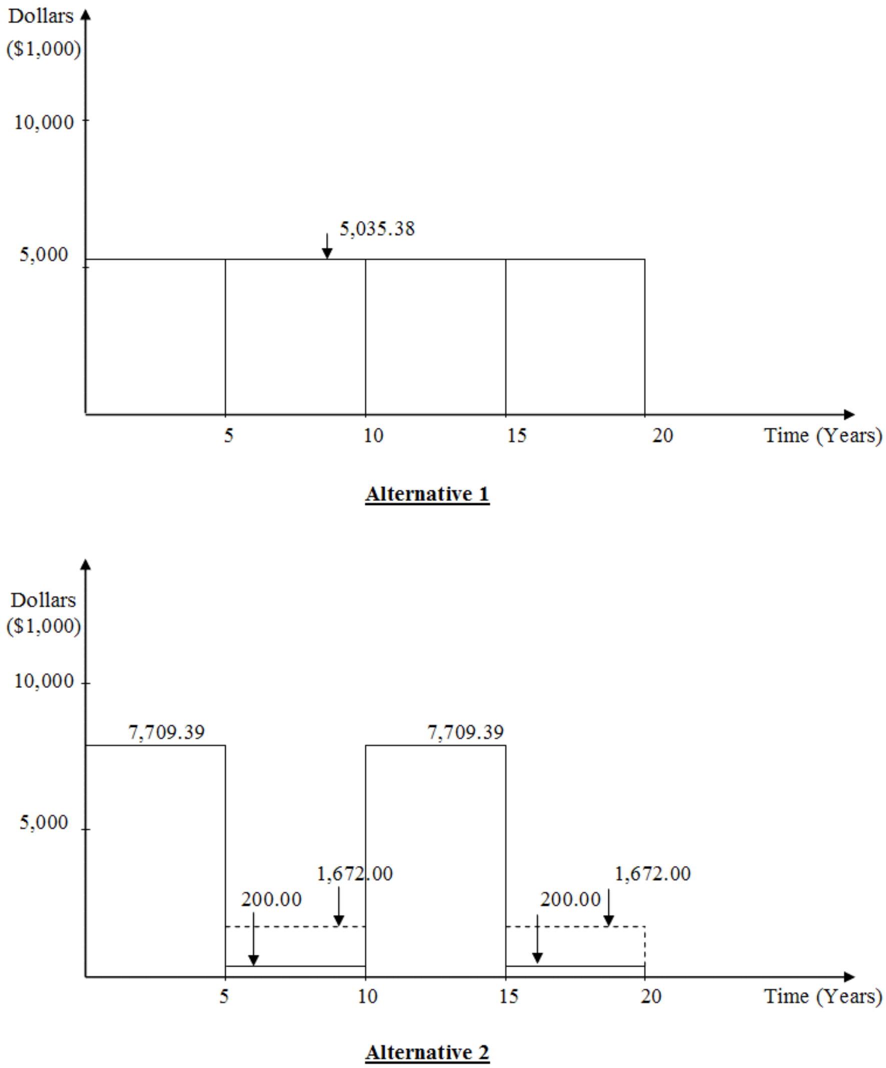


Figure 19. Cost vs. Time Diagrams of project alternatives (Example Two).

5.2.3 Results of the Example

Figure 20 shows the first page of the report and Figure 21 shows results of the deterministic analysis.

RealCost 2.1 Report **12/22/2005**

RealCost Input Data

1. Economic Variables	
Value of Time for Passenger Cars ($/hour)	$9.00
Value of Time for Single Unit Trucks ($/hour)	$24.00
Value of Time for Combination Trucks ($/hour)	$24.00

2. Analysis Options	
Include User Costs in Analysis	Yes
Include User Cost Remaining Service Life Value	Yes
Use Differential User Costs	Yes
User Cost Computation Method	Calculated
Include Agency Cost Remaining Service Life Value	Yes
Traffic Direction	Both
Analysis Period (Years)	20
Beginning of Analysis Period	1997
Discount Rate (%)	4.0

3. Project Details and Quantity Calculations	
State Route	10
Project Name	08-RIV-10
Region	District 08
County	Riverside
Analyzed By	Gov't Mule
Mileposts	
Begin	134.00
End	144.00
Length of Project (miles)	10.00
Comments	

4. Traffic Data	
AADT Construction Year (total for both directions)	22,000
Cars as Percentage of AADT (%)	67.0
Single Unit Trucks as Percentage of AADT (%)	17.0
Combination Trucks as Percentage of AADT (%)	16.0
Annual Growth Rate of Traffic (%)	1.0
Speed Limit Under Normal Operating Conditions (mph)	65
No of Lanes in Each Direction During Normal Conditions	2
Free Flow Capacity (vphpl)	2200
Rural or Urban Hourly Traffic Distribution	Rural
Queue Dissipation Capacity (vphpl)	1750
Maximum AADT (total for both directions)	100,000
Maximum Queue Length (miles)	1.0

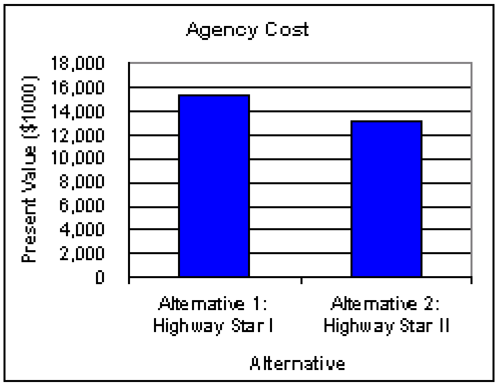
Save As... Close

Figure 20. *RealCost* report (Example Two).

RealCost 2.1 Report **12/22/2005**

Deterministic Results

Total Cost	Alternative 1: Highway Star I		Alternative 2: Highway Star II	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	$20,141.52	$959.70	$15,818.78	$514.71
Present Value	$15,371.79	$723.62	$13,193.02	$427.06
EUAC	$1,131.08	$53.25	$970.77	$31.42



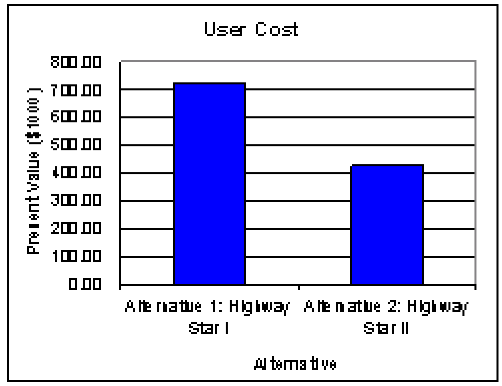


Figure 21. *RealCost* Deterministic Results 1 (Example Two).

Comparison of the results shows that the agency cost for Alternative 2 is 16.5 percent less than it is for Alternative 1. The user cost for Alternative 2 is also substantially less than it is for Alternative 1 (69.5 percent less). Therefore, Alternative 2 is the better option.

Figure 22 shows the results of a what-if scenario in which the maintenance cost of Alternative 2 is increased to $1,672,000 for every five year period. Under this scenario, the agency costs of the alternatives are fairly close (within 10 percent), but the user cost of Alternative 2 is still much less than it is for Alternative 1 since the traffic information was not changed. Therefore, Alternative 2 is still the better option, assuming everything else is equal for the alternatives.

RealCost 2.1 Report **12/22/2005**

Deterministic Results

Total Cost	Alternative 1: Highway Star I		Alternative 2: Highway Star II	
	Agency Cost ($1000)	User Cost ($1000)	Agency Cost ($1000)	User Cost ($1000)
Undiscounted Sum	$20,141.52	$959.70	$18,762.78	$514.71
Present Value	$15,371.79	$723.62	$15,220.24	$427.06
EUAC	$1,131.08	$53.25	$1,119.93	$31.42

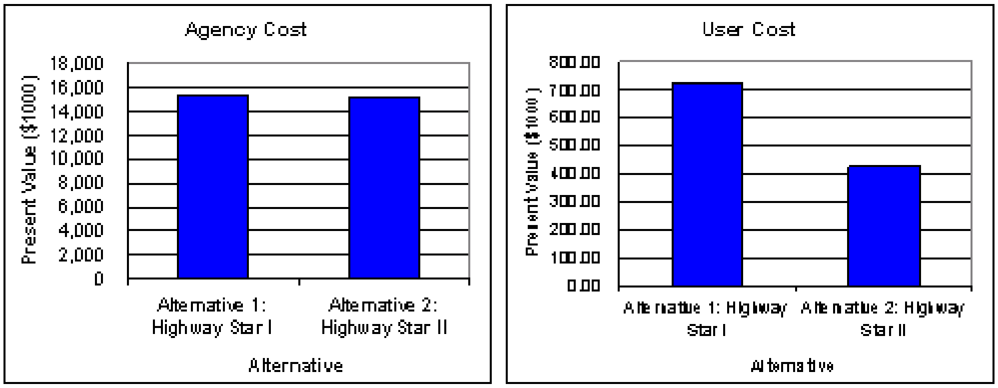


Figure 22. *RealCost* Deterministic Results 2 (Example Two).

REFERENCES

1. Federal Highway Administration, "Life-Cycle Cost Analysis in Pavement Design," FHWA-SA-98-079, Pavement Division Interim Technical Bulletin, September 1998.

2. California Department of Transportation, "2004 State of the Pavement," Division of Maintenance, Office of Roadway Rehabilitation and Roadway Maintenance, July 2005.

3. California Department of Transportation, "HM-1 Major Maintenance Contracts 2004/05 Fiscal Year-End Report," Division of Maintenance, Office of Roadway Maintenance, September 2005.

4. California Department of Transportation, "Highway Design Manual," Fifth Edition, July 2004 with December 2004 Addendum.

5. California Department of Transportation, "Historical Cost Analysis of Capital Outlay Support for FYs 1998 to 2002," Division of Project Management, Office of Project Workload and Data Management, May 2005.

6. Washington State Department of Transportation, "Pavement Type Selection Protocol," Environmental and Engineering Program Division, January 2005.

APPENDIX 1: List of Limitations to and Bugs in *RealCost*

Bug/Question(s)

1. Program appears to calculate salvage value based on a round-down if activity life is in decimal of less than 0.5 year (see Example I).
2. Why are the User Work Zone Cost ($1000) default values different between alternatives? The example included in the WSDOT (Washington State Department of Tranportation) *Pavement Type Protocol* (2005) also has them different within each alternative. How were these defaults determined?
3. No. of lanes open in each direction during work zone: If it is two lanes (one lane in each direction), how is it input in the program? Is there a limitation of two lanes minimum in each direction?
4. Is there a limit to the Queue Length? What is the limit? Program shows warning sign "exceed maximum queue length! Set to maximum queue length," but still calculates. What value of queue does it use to calculate since user cost is very sensitive to queue length?
5. Same with Work Zone Capacity. What does it mean when the warning says, "Projected AADT for Alternative _, Reh_ exceeds 24-hour work zone capacity! Set to 24-hour work zone capacity?"
6. After the Deterministic Results tab is opened and printed, on top of the print it says, "Probabilistic….?"
7. What values/numbers to be input in the Alternatives 1 and 2 when not all six rehab activities are involved? For example, if Alternative 1 has only 3 rehab activities, what do users do with the other three activities? Input the minimum values as described on

the manual or leave them all blank? Leaving them blank give error messages where putting in a minimal value will give warning only.

Limitation(s)

1. Analysis period input has a range of up to forty years.
2. *RealCost* only allows for up to six subsequent maintenance/rehabilitation actions in an alternative life cycle path.

APPENDIX 2: TYPICAL PAVEMENT M&R SCHEDULES FOR CALIFORNIA

The following pavement maintenance and rehabilitation (M&R) schedules are a consolidation of the pavement M&R decision trees (for pavement M&R activity scheduling) included in Caltrans district offices' ten-year pavement plans. Currently, each Caltrans district office has its own set of pavement decision trees, most of which have different sequences of pavement M&R activities, depending on route class (alternatively known maintenance service level) and pavement type. The following compilation of California-specific pavement M&R schedules has been developed to simplify the selection of a schedule for the LCCA process.

The categorization of these California-specific pavement M&R schedules is based on four factors: the climate region, maintenance service level, existing pavement/final surface type, and initial M&R strategy (i.e., project alternatives).

The nine climate regions designated in the "Map of Caltrans Climate Regions" (see Figure 23) are grouped into the four climate regions (i.e., Coastal, Valley, Desert, and Mountain; see Table 12), and the pavement M&R decisions applicable to these four climate regions are collected from the district offices.

If a pavement decision tree for a particular pavement type is not available for a particular climate region, a similar decision tree from another region is used instead. Since the majority of the district offices do not currently have a pavement decision tree for "New" and "Reconstructed" pavements, the pavement M&R activity sequence and service lives presented for these types of pavements are based on engineering judgment and experience.

Note: These pavement M&R schedules assume there will be no early failures due to non-conformance to the specified mix design or poor construction quality.

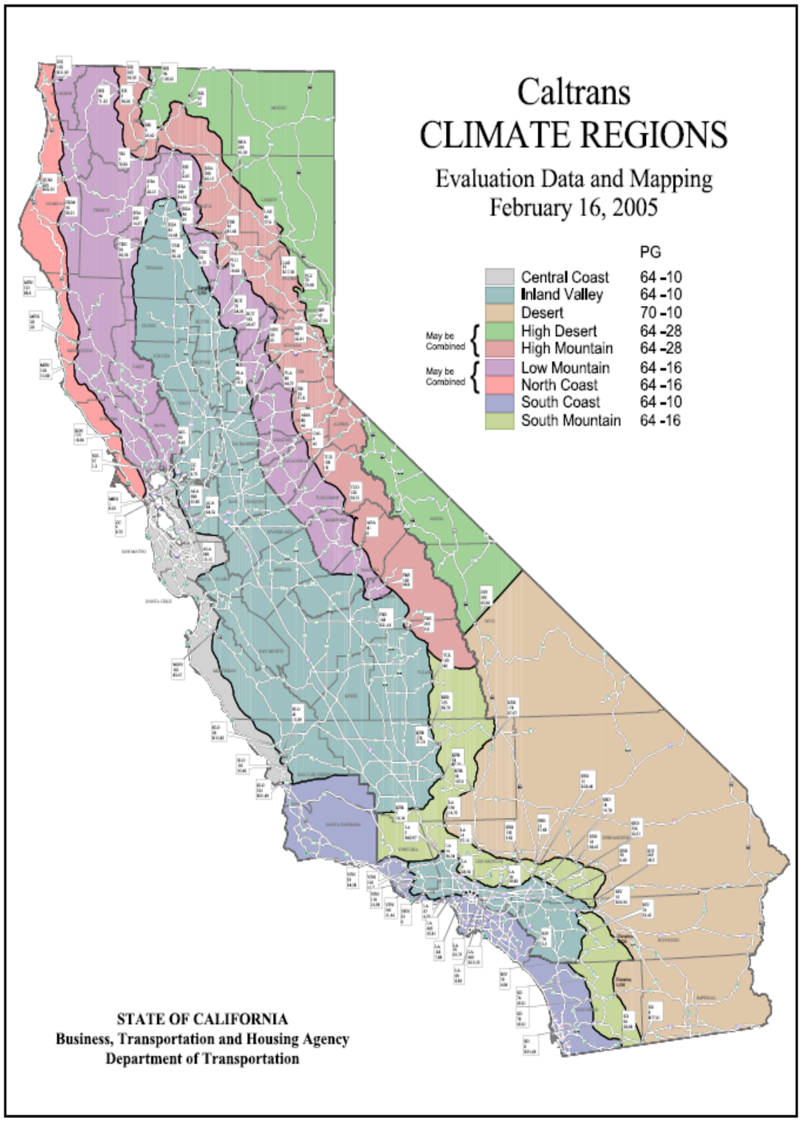


Figure 23. Map of Caltrans Climate Regions.

Table 12. Caltrans Climate Region Classification

Caltrans Climate Regions	Climate Regions for Pavement M&R Schedules
North Coast	Coastal
Central Coast	
South Coast	
Inland Valley	Valley
High Desert	Desert
Desert	
High Mountain	Mountain
Low Mountain	
South Mountain	

Coastal Region: Flexible Pavements (1/3)

Climate Region	Maint. Service Level	Existing Pavement/Final Surface Type	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Coastal	1, 2, 3	Flexible	20yr New Pavement, Rehab 10yr	Year of Action	18	28	38	48	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	24	44			
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)			TBD
			CAPM 5yr	Year of Action	0	10	15	25	
				Strategy	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	ACOL (Rehab 10yr)	ACOL (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	20	40		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD

Coastal Region: Flexible Pavements with OGAC (2/3)

Climate Region	Maint. Service Level	Existing Pavement/Final Surface Type	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Coastal	1, 2, 3	Flexible w/ OGAC	20yr New Pavement, Rehab 10yr	Year of Action	19	34	49	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			20yr New Pavement, Rehab 20yr	Year of Action	20	40		
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)		TBD (Replace OGAC every 4-6 years)
			40yr New Pavement, Rehab 20yr	Year of Action	41			
				Strategy	ACOL w/ OGAC (Rehab 20yr)			TBD (Replace OGAC every 4-6 years)
			CAPM 5yr	Year of Action	0	10	20	
				Strategy	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	TBD (Replace OGAC every 4-6 years)
			CAPM 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 20yr	Year of Action	0	25	50	
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 40yr	Year of Action	0	40		
				Strategy	ACOL w/ OGAC (Rehab 40yr)	ACOL w/ OGAC (Rehab 40yr)		TBD (Replace OGAC every 4-6 years)

Coastal Region: Flexible Pavements with RAC (3/3)

Climate Region	Maint. Service Level	Existing Pavement/Final Surface Type	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Coastal	1, 2, 3	Flexible w/ RAC	20yr New Pavement, Rehab 10yr	Year of Action	16	26	36	46	
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	16	26	42		
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)		TBD
			CAPM 5yr	Year of Action	0	8	17	25	
				Strategy	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 20yr	Year of Action	0	16	28	44	
				Strategy	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	TBD

Valley Region: Flexible Pavements (1/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Valley	Flexible	1 & 2	20yr New Pavement, Rehab 10yr	Year of Action	14	24	34	44	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	14	34			
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)			TBD
			CAPM 5yr	Year of Action	0	12	24		
				Strategy	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)		TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	20	40		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD
		3	20yr New Pavement, Rehab 10yr	Year of Action	16	26	36		
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)		TBD
			20yr New Pavement, Rehab 20yr	Year of Action	16	40			
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)			TBD
			CAPM 5yr	Year of Action	0	9	19		
				Strategy	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)		TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	20	40		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD

Valley Region: Flexible Pavements with OGAC (2/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Valley	Flexible w/ OGAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	19	34	49	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			20yr New Pavement, Rehab 20yr	Year of Action	19	40		
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)		TBD (Replace OGAC every 4-6 years)
			40yr New Pavement, Rehab 20yr	Year of Action	40			
				Strategy	ACOL w/ OGAC (Rehab 20yr)			TBD (Replace OGAC every 4-6 years)
			CAPM 5yr	Year of Action	0	10	20	
				Strategy	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	TBD (Replace OGAC every 4-6 years)
			CAPM 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 20yr	Year of Action	0	25	50	
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 40yr	Year of Action	0	40		
				Strategy	ACOL w/ OGAC (Rehab 40yr)	ACOL w/ OGAC (Rehab 40yr)		TBD (Replace OGAC every 4-6 years)

Valley Region: Flexible Pavements with RAC (3/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy							Annual Maint. Cost (HM-1)
Valley	Flexible w/ RAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	15	23	37	43	45	
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	Crack Seal/ Dig Out	ACOL w/ RAC (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	15	23				
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)				TBD
			CAPM 10yr	Year of Action	0	8	16			
				Strategy	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 5yr)			TBD
			CAPM 10yr	Year of Action	0	10	18	26	34	
				Strategy	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	10	18	26	34	
				Strategy	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	18	27			
				Strategy	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)			TBD

Desert Region: Flexible Pavements (1/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Desert	Flexible	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	18	32	46	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	18	42		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD
			CAPM 5yr	Year of Action	0	9	19	
				Strategy	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	14	28	
				Strategy	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	14	28	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	26		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD

Desert Region: Flexible Pavements with OGAC (2/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Desert	Flexible w/ OGAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	19	34	49	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			20yr New Pavement, Rehab 20yr	Year of Action	19	40		
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)		TBD (Replace OGAC every 4-6 years)
			40yr New Pavement, Rehab 20yr	Year of Action	40			
				Strategy	ACOL w/ OGAC (Rehab 20yr)			TBD (Replace OGAC every 4-6 years)
			CAPM 5yr	Year of Action	0	10	20	
				Strategy	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	TBD (Replace OGAC every 4-6 years)
			CAPM 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 10yr	Year of Action	0	15	30	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 20yr	Year of Action	0	25	50	
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	TBD (Replace OGAC every 4-6 years)
			Rehab 40yr	Year of Action	0	40		
				Strategy	ACOL w/ OGAC (Rehab 40yr)	ACOL w/ OGAC (Rehab 40yr)		TBD (Replace OGAC every 4-6 years)

Desert Region: Flexible Pavements with RAC (3/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Desert	Flexible w/ RAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	16	26	36	46	
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	16	26	36	46	
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	TBD
			CAPM 5yr	Year of Action	0	8	17	25	
				Strategy	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 20yr	Year of Action	0	16	28	44	
				Strategy	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	TBD

Mountain Region: Flexible Pavements (1/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy					Annual Maint. Cost (HM-1)
Mountain	Flexible	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	22	37		
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)		TBD
			20yr New Pavement, Rehab 20yr	Year of Action	22	42		
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)		TBD
			CAPM 5yr	Year of Action	0	12	24	
				Strategy	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	ACOL (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	15	30	
				Strategy	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	TBD
			Rehab 10yr	Year of Action	0	15	30	
				Strategy	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	ACOL (Rehab 10yr)	TBD
			Rehab 20yr	Year of Action	0	24	48	
				Strategy	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)	ACOL (Rehab 20yr)	TBD

Mountain Region: Flexible Pavements with OGAC (2/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Mountain	Flexible w/ OGAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	19	34	39	41	
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	Dig Out	Replace OGAC	TBD (Replace OGFC every 4-6 years)
			20yr New Pavement, Rehab 20yr	Year of Action	19	44	52		
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)	Dig Out		TBD (Replace OGFC every 4-6 years)
			40yr New Pavement, Rehab 20yr	Year of Action	40				
				Strategy	ACOL w/ OGAC (Rehab 20yr)				TBD (Replace OGFC every 4-6 years)
			CAPM 5yr	Year of Action	0	11	18		
				Strategy	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)	ACOL w/ OGAC (CAPM 5yr)		TBD (Replace OGFC every 4-6 years)
			CAPM 10yr	Year of Action	0	15	30		
				Strategy	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)	ACOL w/ OGAC (CAPM 10yr)		TBD (Replace OGFC every 4-6 years)
			Rehab 10yr	Year of Action	0	15	30		
				Strategy	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)	ACOL w/ OGAC (Rehab 10yr)		TBD (Replace OGFC every 4-6 years)
			Rehab 20yr	Year of Action	0	30			
				Strategy	ACOL w/ OGAC (Rehab 20yr)	ACOL w/ OGAC (Rehab 20yr)			TBD (Replace OGFC every 4-6 years)
			Rehab 40yr	Year of Action	0	45			
				Strategy	ACOL w/ OGAC (Rehab 40yr)	ACOL w/ OGAC (Rehab 40yr)			TBD (Replace OGFC every 4-6 years)

Mountain Region: Flexible Pavements with RAC (3/3)

Climate Region	Existing Pavement/Final Surface Type	Maint. Service Level	Initial M&R Strategy						Annual Maint. Cost (HM-1)
Mountain	Flexible w/ RAC	1, 2, 3	20yr New Pavement, Rehab 10yr	Year of Action	16	26	36	46	
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	TBD
			20yr New Pavement, Rehab 20yr	Year of Action	16	26	42		
				Strategy	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)		TBD
			CAPM 5yr	Year of Action	0	8	17	25	
				Strategy	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 5yr)	AR Chip Seal (CAPM 5yr)	TBD
			CAPM 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (CAPM 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 10yr	Year of Action	0	10	20	30	
				Strategy	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 10yr)	AR Chip Seal (CAPM 5yr)	TBD
			Rehab 20yr	Year of Action	0	16	28	44	
				Strategy	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	ACOL w/ RAC (Rehab 20yr)	AR Chip Seal (CAPM 5yr)	TBD

All Regions: Rigid Pavements (1/1)

Climate Region	Maint. Service Level	Existing Pavement/Final Surface Type	Initial M&R Strategy											Annual Maint. Cost (HM-1)
All	1, 2, 3	PCC	CAPM 5yr	Year of Action	0	5	10	15	20	30	35	40	45	
				Strategy	5% Slab Repl (CAPM 5yr)	Grind PCC (CAPM 5yr)	5% Slab Repl (CAPM 5yr)	Grind PCC (CAPM 5yr)	Crack Seat & OL (CAPM 10yr)	5% Slab Repl (CAPM 5yr)	Grind PCC (CAPM 5yr)	5% Slab Repl (CAPM 5yr)	Grind PCC (CAPM 5yr)	TBD
		PCC + ACOL	CAPM 10yr	Year of Action	0	9	18	27	36	45				
				Strategy	ACOL+5% Slab Replacement (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL (CAPM 10yr)	ACOL+5% Slab Replacement (CAPM 10yr)	ACOL (CAPM 10yr)				TBD
		PCC + ACOL	CAPM 10yr	Year of Action	0	10	20	30	40	50				
				Strategy	Grind + 5% Slab Repl (CAPM 10yr)	Crack Seat & OL (CAPM 10yr)	Grind + 5% Slab Repl (CAPM 10yr)	Crack Seat & OL (CAPM 10yr)	Grind + 5% Slab Repl (CAPM 10yr)	Crack Seat & OL (CAPM 10yr)				TBD
		PCC	Rehab 20yr	Year of Action	0	10	20	30	40	50				
				Strategy	Lane Repl (Rehab 20yr)	Crack Seal	Unbond PCC OL (Rehab 20yr)	Crack Seal	Crack Seat & OL (Rehab 20yr)	Crack Seal				TBD
		PCC	20yr New Pavement, Rehab 20yr	Year of Action	10	20	30	40	50					
				Strategy	Crack Seal	Lane Repl (Rehab 20yr)	Crack Seal	Unbond PCC OL (Rehab 20yr)	Crack Seal					TBD
		PCC	20yr New Pavement, Rehab 40yr	Year of Action	10	20	35	45	60					
				Strategy	Crack Seal	Lane Repl (Rehab 40yr)	Crack Seal	Crack Seat & OL (CAPM 5yr)	Unbond PCC OL (Rehab 40yr)					TBD

APPENDIX 3: Maximum Queue Length Estimation

The maximum number of queued vehicles during which the work zone is in effect is estimated by the traffic demand-capacity model, as shown in **Error! Reference source not found.**. When demand exceeds capacity, the queue starts to build up. The maximum number of queued vehicles is measured where the difference between the demand curve and the capacity curve is the greatest. Then the maximum queue length can be obtained by multiplying the maximum number of queued vehicles by the average vehicle length (i.e., 40 ft.).

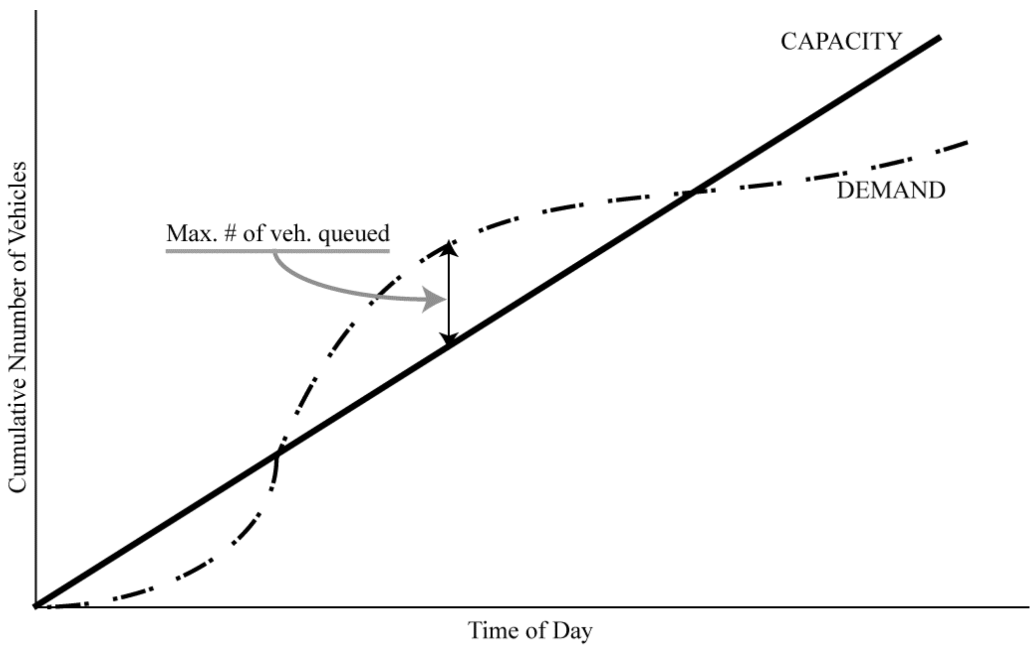


Figure 24. Traffic Demand-Capacity Model.

Sample Maximum Queue Length Estimation

During construction on a three-lane urban freeway section, one lane will be closed and two lanes will be open. The work zone capacity is assumed as 1,600 pcphpl (passenger cars per hour per lane). The hourly traffic demands, expressed in vehicle per hour (vph), are assumed to be those shown in the second column in Figure 24. Ten percent of the traffic volume is assumed to be occupied by single-unit and combination trucks. The procedure for estimating the maximum queue length are:

- The hourly passenger car capacity of one lane (1,600 pcphpl) of the work zone is converted to the hourly vehicular capacity of one lane [1,524 vphpl (vehicles per hour per lane)] of the work zone using the following equation:

  $$vphpl = pcphpl \times f_{HV}$$

  where *vphpl* = vehicle per hour per lane
  pcphpl = passenger car per hour per lane.

  $$f_{HV} = \frac{100}{[100 + P \times (E - 1)]}$$

  where
  f_{HV} = heavy vehicle adjustment factor (vehicle/passenger car),
  P = percentage of heavy vehicles, and
  E = passenger car equivalent (passenger cars/heavy vehicle).
  Refer to the table below for an E value corresponding to a type of terrain at the project site)

	Type of Terrain		
	Level	**Rolling**	**Mountainous**
E	1.5	2.5	4.5

Table 13. Maximum Queue Length Estimation

Hour	Volume (vph)	Capacity (pcphpl)	Capacity (vphpl)	No. of lanes open	Capacity (vph)	Queued veh.	
1	340	1,600	1,524	2	3,048	0	
2	350	1,600	1,524	2	3,048	0	
3	350	1,600	1,524	2	3,048	0	
4	400	1,600	1,524	2	3,048	0	
5	800	1,600	1,524	2	3,048	0	
6	1,200	1,600	1,524	2	3,048	0	
7	3,000	1,600	1,524	2	3,048	0	
8	3,400	1,600	1,524	2	3,048	352	
9	3,600	1,600	1,524	2	3,048	904	
10	3,000	1,600	1,524	2	3,048	856	
11	1,800	1,600	1,524	2	3,048	0	
12	1,300	1,600	1,524	2	3,048	0	
13	1,200	1,600	1,524	2	3,048	0	
14	1,000	1,600	1,524	2	3,048	0	
15	1,200	1,600	1,524	2	3,048	0	
16	1,900	1,600	1,524	2	3,048	0	
17	3,400	1,600	1,524	2	3,048	352	
18	3,650	1,600	1,524	2	3,048	954	
19	2,400	1,600	1,524	2	3,048	306	
20	1,000	1,600	1,524	2	3,048	0	
21	800	1,600	1,524	2	3,048	0	
22	760	1,600	1,524	2	3,048	0	
23	300	1,600	1,524	2	3,048	0	
24	300	1,600	1,524	2	3,048	0	
			Max. queued veh.			954	
			Max. queued veh. on 3 lanes			318	
			Average vehicle length			40	ft
			Max. queue length			12,720	ft
						2.41	mi

- As shown in Table 13, the queue starts at 8 AM when the traffic demand (3,400 vph) exceeds the work zone capacity (3,048 vph) and dissipates at 11 AM when the sum of the hourly demand (1,800 vph) and the number (856) of queued vehicles becomes less than the work zone capacity. The queue starts again at 5 PM when the traffic demand (3,400 vph) exceeds the work zone capacity (3,048 vph).

- The maximum number of queued vehicles is 954 at 6 PM when the number of the queued vehicles is the greatest. The maximum number of queued vehicles per lane is then 318 [954 (vehicles) divided by 3 (lanes)]. Thus, the maximum queue length from the work zone operation is estimated at 2.41 mile [318 (vehicles) multiplied by 40 ft (average vehicle length)].

APPENDIX 4. STATE HIGHWAY TRAFFIC HOURLY DISTRIBUTIONS

Weekday Only:

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.62	48.8	51.2	0.9	48.0	52.0
1 - 2	1.30	52.1	47.9	0.6	49.5	50.5
2 - 3	1.30	53.5	46.5	0.6	51.9	48.1
3 - 4	1.52	59.3	40.7	0.8	56.8	43.2
4 - 5	2.14	62.1	37.9	1.6	61.3	38.7
5 - 6	3.43	59.8	40.2	3.1	60.3	39.7
6 - 7	4.79	58.5	41.5	5.0	58.4	41.6
7 - 8	5.30	57.8	42.2	6.0	57.6	42.4
8 - 9	5.12	56.0	44.0	5.8	55.9	44.1
9 - 10	5.10	54.3	45.7	5.5	53.9	46.1
10 - 11	5.24	52.5	47.5	5.4	51.4	48.6
11 - 12	5.43	51.2	48.8	5.8	50.1	49.9
12 - 13	5.63	50.9	49.1	6.0	49.1	50.9
13 - 14	5.74	51.2	48.8	6.1	48.4	51.6
14 - 15	6.11	50.3	49.7	6.5	46.3	53.7
15 - 16	6.57	48.8	51.2	7.0	44.6	55.4
16 - 17	6.73	47.5	52.5	7.0	43.4	56.6
17 - 18	6.40	45.2	54.8	6.5	43.4	56.6
18 - 19	5.32	45.6	54.4	5.4	44.4	55.6
19 - 20	4.31	44.6	55.4	4.2	44.8	55.2
20 - 21	3.57	45.6	54.4	3.5	45.4	54.6
21 - 22	3.03	46.0	54.0	2.9	45.9	54.1
22 - 23	2.40	47.1	52.9	2.2	47.2	52.8
23 - 24	1.88	47.1	52.9	1.4	45.1	54.9
	100.0			100.0		

Weekend Only:

Hour	AADT Rural (%)	Inbound Rural (%)	Outbound Rural (%)	AADT Urban (%)	Inbound Urban (%)	Outbound Urban (%)
0 - 1	1.91	47.6	52.4	1.8	47.7	52.3
1 - 2	1.61	49.5	50.5	1.3	47.8	52.2
2 - 3	1.32	49.0	51.0	0.9	46.5	53.5
3 - 4	1.52	54.9	45.1	0.8	52.2	47.8
4 - 5	1.64	54.9	45.1	0.9	56.3	43.7
5 - 6	2.13	53.0	47.0	1.5	55.5	44.5
6 - 7	2.86	50.8	49.2	2.4	53.2	46.8
7 - 8	3.58	50.4	49.6	3.4	51.6	48.4
8 - 9	4.38	50.0	50.0	4.6	50.9	49.1
9 - 10	5.22	50.7	49.3	5.5	50.2	49.8
10 - 11	5.96	51.3	48.7	6.2	49.8	50.2
11 - 12	6.46	50.6	49.4	6.7	49.1	50.9
12 - 13	6.58	50.9	49.1	7.0	48.7	51.3
13 - 14	6.58	51.3	48.7	7.0	48.5	51.5
14 - 15	6.66	52.4	47.6	7.1	47.9	52.1
15 - 16	6.89	53.1	46.9	7.0	48.1	51.9
16 - 17	6.73	52.9	47.1	6.7	47.9	52.1
17 - 18	6.21	52.6	47.4	6.3	48.4	51.6
18 - 19	5.54	51.5	48.5	5.7	48.4	51.6
19 - 20	4.77	50.7	49.3	5.0	48.9	51.1
20 - 21	4.02	51.4	48.6	4.2	48.8	51.2
21 - 22	3.28	51.4	48.6	3.5	49.5	50.5
22 - 23	2.60	50.7	49.3	2.7	49.6	50.4
23 - 24	1.54	48.6	51.4	1.6	49.8	50.2
	100.0			100.0		